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TRANSACTIONS

OF THE

ROYAL SOCIETY OF SOUTH AFRICA

VOLUME II.

1910–1912.

WITH THIRTEEN PLATES.

OHIO STATE UNIVERSITY

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1912.

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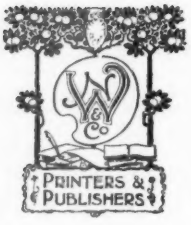

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MINUTES OF PROCEEDINGS

OF THE

ROYAL SOCIETY OF SOUTH AFRICA.

ORDINARY MONTHLY MEETING.

March 16, 1910.

The President, S. S. HOUGH, F.R.S., Esq., in the Chair.

Nominations: D. DOD, S. Rhodesia, by L. PÉRINGUEY and R. M. LIGHTFOOT; Dr. DRU-DRURY, Graham's Town, by S. S. HOUGH and L. PÉRINGUEY; A. M. GUEST, Klerksdorp, by L. PÉRINGUEY and R. M. Lightfoot; J. A. HAFFE, A.M.I.E.E., Cape Town, by A. M. WILSON and L. PÉRINGUEY; Dr. E. E. MOSSOP, by A. M. WILSON and L. PÉRINGUEY; Dr. PÖCH, Vienna, by A. W. ROGERS and L. PÉRINGUEY; Dr. F. W. WEBER, M.D., Paarl, by A. M. WILSON and L. PÉRINGUEY; W. H. LOGEMAN, M.A., Cape Town, by J. C. BEATTIE and L. PÉRINGUEY; A. E. SNAPE, M.Sc., A.M.I.C.E., by H. BOHLE and L. CRAWFORD.

Dr. L. PÉRINGUEY exhibited some ingot moulds found amongst a heap of iron slags from ancient workings in Mudza-Macequace, Portuguese East Africa, still containing the crude iron as poured from the fusions; on one portion are some markings which must have been cut in the clay before baking. The sender, Mr. A. H. Exton, stated that he found also several pieces of talcose schist with markings upon them, and of which he sent a copy; these markings, however, are similar to an example found at Zimbabwe by Bent, and now in the South African Museum. This alleged inscription was submitted by Dr. Schlichter to all the *cognoscenti* in Europe and pronounced not to be an inscription. As for the cylinders of clay containing the iron, they are quite similar to the clay nozzles used by the native smiths for affixing to their bellows.

Dr. R. MARLOTH read a paper, "Some New South African Succulents,"

and exhibited some of the specimens. Among the new species are some of special biological interest. *Mesembrianthemum mitratum* was discovered in the desert belt east of Port Nolloth by Mr. Garwood Alston. The shrub bears at the end of the apparently dead branches a fleshy knob. This consists of two closely joined leaves, between which the flower appears. Flower and fruit are then fed by the sap of the knob until fully developed, when nothing is left of the sheltering knob except its skin. Another species of *Mesembrianthemum* takes the same care of its flower and fruit, nursing them within its own body; but it is even more cautious than its big brother, for it buries itself entirely in the ground and shows only the apex of its few leaves. As the ends of the leaves are flat, flush with the ground, and coloured exactly like the rusty gravel, it is practically impossible to detect them when they are not in flower. *Euphorbia elastica* is the species from which some sort of rubber has been manufactured in Little Namaqualand, and although the quality was not good, it is not impossible that with the present boom in rubber, even those barren deserts may see a flourishing industry.

The following papers were read:—

"Variation of Gravity," by Dr. R. A. Lehfeldt. There have been differences of opinion as to the way in which the value of gravity is affected by height above sea-level, and special interest attaches to measurements on a really larger table-land. The result of observations taken at Johannesburg and Vereeniging is that the variation per meter is 0·000236, considerably less than that given by Helmert. At the Royal Observatory, Cape Town, gravity is 979·714 (observed value).

"The Ovule of the *Bruniaceæ*," by W. T. Saxton, M.A., F.L.S. The main point brought out in this paper is that the ovule in the *Bruniaceæ* is pendulous and anatropous with a dorsal raphe. There is a simple massive integument with a long slender micropyle. In the genus *Brunia* the embryo-sac is packed with starch and is all that remains of the nucellus, while in *Berzelia* and *Staavia* a little of the basal nucellar tissue persists. The only conclusion to be drawn from the study is the same to which Schönland was led, viz., that the *Bruniaceæ* are very isolated in the cohort to which they are usually attached. The single integument might be regarded as a primitive character if it were not associated with the ovule of the *Compositæ*, while in some of those orders usually regarded as primitive (*e.g.*, *Proteaceæ*) two integuments are found. The other characters of the ovule rather tend to agree with essentially modern types (*e.g.*, *Compositæ*) than with primitive (*e.g.*, *Ranunculaceæ*).

"On *Chrysochloris Namaquensis*, Broom," by R. Broom. *Chrysochloris Namaquensis* was named from skulls found at Garies in the disgorged pellets of owls. A description is now given of the skin. A remarkable feature of the species is that the third molar is about as

frequently absent as present. The skulls with thirty-six teeth had been named *C. tenuis*, but as out of seven known skulls three have ten teeth on both sides, two have nine teeth on both sides, and two have ten on the one side and nine on the other, *C. tenuis* must now be regarded as a synonym of *C. namaquensis*. Further, the genus *Amblysomus* which was founded for those species with thirty-six teeth becomes invalid, as was previously argued by the writer on other grounds.

"Why the White Crow gives no Sound,"—a folk-lore collected from an old Hottentot by the late Rev. E. NEETHLING.

ANNIVERSARY MEETING.

April 20, 1910.

The TREASURER presented the Financial Report for the past year.

The SECRETARY presented his Report for the past year.

The PRESIDENT gave his Anniversary Address.

REPORT OF THE SECRETARY

For the Year 1909.

The number of Honorary Fellows is 5; of Fellows 44; of Members 152; or an increase of 4 in the number of Fellows, and a decrease of 8 in that of Members.

Seven Ordinary Meetings and the Anniversary Meeting were held during the year, and the following papers read:—

"Note on a Theorem regarding a Sum of the Differential-coefficients of Principal Minors of a Jacobian," by T. MUIR.

"The Spectrum of the Ruby: a New Characteristic Test," by J. MOIR.

"Remarks on some Experiments with Snake Venom," by W. FREI.

"An Upper Limit for the Value of a Determinant," by T. MUIR.

"Note on a Cœnurus of the Duikerbok," by L. GOUGH.

"The Evolution of the River System of Griqualand West," by A. L. DU TOIT.

"The Rainfall of South Africa: the Possibility of Prediction over the South-West," by A. G. HOWARD.

"On some Points in the Morphology and Biology of a New Species of Haworthia," by S. SCHÖNLAND.

"On the Absorption of Water by the Aerial Organs of some Succulents," by S. SCHÖNLAND.

"Some New South African Succulents," by R. MARLOTH.

"Note on an Abnormal Seedling of *Widdringtonia cupressoides* and a brief account of the Vascular System of the Normal Seedling," by H. S. MORRIS.

"The Genesis of the Chemical Elements," by J. MOIR.

"Evaporation in a Current of Air," by J. R. SUTTON.

"Notes on the Absorption of Water by Aerial Organs of Plants," by R. MARLOTH.

"Statement of Silayi with Reference to His Life among the Bushmen," by W. E. STANFORD.

"On some Flowering Plants from the Neighbourhood of Port Elizabeth," by S. SCHÖNLAND.

"Borchard's Form of the Eliminant of Two Equations of the *n*th Degree," by T. MUIR.

"Revised List of the Flora of Natal," by J. MEDLEY WOOD.

"On the Relationship of the South African Fossil Reptiles to those of Other Parts of the World," by R. BROOM.

"On Nutmeg Poisoning," by M. WILSON.

"Observations on some Specimens of South African Fossil Reptiles preserved in the British Museum," by R. BROOM.

"The Odyssey of our Bushman Boy," by Miss CURRLÉ.

"Notes on Zoological and Botanical Collections from the Group of Islands of Tristan d'Acunha," by L. PÉRINGUEY and E. T. PHILLIPS.

"Absorption of Light by the Atmosphere," by A. W. ROBERTS.

"The Ovule of the *Bruniaceæ*," by W. T. SAXTON.

"Some New South African Succulents (pt. 3)," by R. MARLOTH.

"Gravity on the South African Tableland," by R. A. LEHFELD.

"On *Chrysochloris namaquensis*," by R. BROOM.

Vol I., containing 515 pages and 27 plates, has been issued during the 1909 and 1910 session.

Nine papers read at the last two meetings are already in proof-sheets and will form Part I. of Vol. II.

In term of the resolution adopted at the Anniversary Meeting, the Council have examined the documents in possession of the Society and have prepared the following statements of accounts: I. July 1, 1907, to May 27, 1908, at which time the Philosophical Society handed over its balance to the Royal Society. II. May 28, 1908, to December 31, 1908. III. January 1, 1909, to December 31, 1909. The Council is satisfied that these are true accounts.

L. PÉRINGUEY, *Secretary.*

TREASURER'S STATEMENT.

THE TREASURER IN ACCOUNT WITH THE SOUTH AFRICAN PHILOSOPHICAL SOCIETY, JULY 1, 1907, TO MAY 27, 1908.

RECEIPTS.	£	s.	d.	EXPENDITURE.	£	s.	d.
To Balance in Bank on fixed deposit	100	0	0	By Publications and Printing	207	17	8
,, Balance in Bank as per Pass Book	141	15	6	,, Freight, Insurance, Landing Charges	13	10	4
,, Balance in hand, Petty Cash	7	2	9	,, Attendance and Clerical help	8	15	0
,, Subscriptions and Commissions	208	8	9	,, Compilation of Scientific Catalogue	10	0	0
,, Sale of Transactions	65	15	10	,, Expenses of Charter	95	2	0
,, Refund of overpaid account	2	8	9	,, Lamarck Subscription	5	0	0
,, Contributions to Publications by Mr. Medley Wood	25	0	0	,, Stamp and Petties	61	10	7
,, Balance due to Petty Cash account	4	5	1	,, Bank charges	2	16	3
				,, Balance in Bank on fixed deposit	100	0	0
				,, Balance in Bank, as per Pass Book	50	4	10
	£554	16	8		£554	16	8

TREASURER'S STATEMENT.

THE TREASURER IN ACCOUNT WITH THE ROYAL SOCIETY OF SOUTH AFRICA, MAY 28, 1908, TO DECEMBER 31, 1908.

RECEIPTS.	£	s.	d.	EXPENDITURE.	£	s.	d.
To Balance in Bank on fixed deposit	100	0	0	By Balance due to Petty Cash Account	4	5	1
,, Balance in Bank as per Pass Book	50	4	10	,, Publications	214	2	6
,, Interest received on money at fixed deposit, when transferred to current account	5	19	3	,, Illustrations for Publications	30	0	0
,, Subscriptions and Commissions	153	12	0	,, Local Printing	19	15	10
,, Sale of Transactions	39	0	5	,, Freight, Insurance, Landing Charges	3	1	0
				,, Postages and Petties	26	18	11
				,, Bank charges	1	4	3
				,, Compilation of Scientific Catalogue	10	0	0
				,, Attendance and Clerical assistance	10	0	0
				,, Balance in Bank as per Pass Book	28	9	11
				,, Balance in hand, Petty Cash	0	19	0
	£348	16	6		£348	16	6

TREASURER'S STATEMENT.

THE TREASURER IN ACCOUNT WITH THE ROYAL SOCIETY OF SOUTH AFRICA, JANUARY 1, 1909, TO DECEMBER 31, 1909.

RECEIPTS.

	£ s. d.	£ s. d.
To Balance in Bank as per Pass Book		28 9 11
,, Balance in hand, Petty Cash		0 19 0
,, Subscriptions received in 1909:		
for 1907, 4 Town at £2, 1 Country at £1	9 0 0	
for 1908, 1 Fellow at £2, 1 balance Fellow's sub., £1, 7 Town at £2, 4 Country at £1	21 0 0	
for 1909, 36 Fellows at £2, 1 balance Fellow's sub., £1, 49 Town at £2, 83 Country at £1 ..	254 0 0	
for 1910, 1 Town at £2, 2 Country at £1	4 0 0	
		288 0 0
,, Entrance Fees received, 15 new members..		15 0 0
,, Commissions received with members' cheques		1 5 0
,, Sale of Publications (1908) through Wesley & Co.		10 7 6
,, Sale of Publications (1900) less 1s. charge on draft, £6 12s. 9d., from Wesley & Co.		15 6 3
,, Sale of Publications to Government		65 0 0
		£424 7 8

EXPENDITURE.

	£ s. d.
By Publications	308 10 0
,, Local Printing	21 15 5
,, Freight, Insurance, Landing Charges	8 9 8
,, Postages and Petties	52 11 0
,, Stationary	1 17 6
,, Bank Charges for Stamps, Commissions, &c.	2 8 9
,, Cheque Book	0 10 0
,, Compilation of Scientific Catalogue..	10 0 0
,, Clerical assistance in year	5 0 0
,, Charges *re* Room for Meetings	5 0 0
,, Balance in Bank, as per Pass Book	5 6 10
,, Balance in hand, Petty Cash	2 18 6
	£424 7 8

ANNIVERSARY MEETING OF THE SOCIETY, RESUMED

May 18, 1910.

The President, S. S. HOUGH, Esq., F.R.S., in the Chair.

The Statement of Accounts was presented.
The Meeting resolved itself into an Ordinary Meeting.

Elections :—
H. B. SMITH, L. CURRLÉ, D. DRU-DRURY, I. M. GUEST, J. A. HAFFE, Dr. E. E. MOSSOP, DELANCEY DODD, Dr. R. PÖCH, Dr. F. W. WEBER, W. H. LOGEMAN, A. E. SNAPE, Dr. W. JOHNSTON.

Communications :—
" Some Further Observations on the Biology of *Roridula*," by Dr. R. MARLOTH.

Roridula dentata, commonly called the fly-bush, is a shrub one to four feet high, growing on the mountains near Tulbagh and on the Cedar Mountains. As the leaves are provided with many stalked glands, which secrete a very viscid fluid, numerous insects adhere to the leaves and perish there, hence the shrublet is universally considered to be an insectivorous plant. Experiments, however, have shown that the fluid secreted by the glands does not possess any digestive properties and that it is quite different from the fluid secreted by droseraceous plants.

The fluid is a kind of balsam, and probably affords protection to the plant against the attacks of creeping animals, such as snails, caterpillars, ear-wigs, &c., and the capturing of other insects is merely accidental and of no advantage to the plant.

Roridula dentata and *R. Gorgonias*, the only two species of this genus, are consequently to be excluded from the list of insectivorous plants.

" The Absorption-spectrum of Oxygen and a New Law of Spectra," by Dr. J. MOIR. The AB and *a* lines of the Solar-spectrum which are due to absorption by terrestrial oxygen have each a complicated rhythmic structure. The author has discovered an algebraical formula whereby each line can be calculated from a fundamental, the differences being directly proportional to the squares of the first 15 or 16 integers. The agreement is practically in all cases within the observational error. The oxygen molecule is shown to be very slightly unsymmetrical.

" Notes on some Bushmen," by Dr. L. PÉRINGUEY. Owing to the lateness of the hour only a summary of the paper was given. The small, elf-like Bushman was legendary with all the concomitants of the legend. If careful comparison of the description of the old authors, such as Sparrman, Barrow, and Burchell, with the remnants of that so-called

Bush-race was made, it would be found that such physical peculiarities in male or female of which the authors spoke were most accurately described. (Photographs of the casts made at the Cape Town Museum were exhibited proving this contention.) Yet the skull of the brother of one of the females exhibited came within the measurements assigned to Hottentots. This was another proof of the conclusion arrived at by Shrubsall that the Hottentots and the so-called Bush people are closely allied, whereas the akin race, "Strand Looper," show more differentiation. The caves or rock-shelter dwellers of this race, or sub-race, have given, and are giving still, evidence of a superior culture which connects them nevertheless with the rock-painters. The burial of the dead was also dissimilar, flat pieces of stone, some with paintings, it is alleged, being placed over the body, &c.; and the industry would seem to correspond in type, but of course not chronologically to the Magdalenian of Europe, if not to the Aurignacian.

MINUTES OF PROCEEDINGS

OF THE

ROYAL SOCIETY OF SOUTH AFRICA.

ORDINARY MONTHLY MEETING.

June 15, 1910

The President, S. S. HOUGH, Esq., F.R.S., in the Chair.

A letter from His Excellency the Administrator was read announcing that he had received a telegram from the Right Honourable the Secretary of State for the Colonies, conveying the thanks of their Majesties the King and Queen, Queen Alexandra, and the Royal Family, to the Royal Society of South Africa for their kind message of sympathy.

Dr. A. THEILER communicated a note on *Anaplasma marginale*, a new Genus and Species of the *Protozoa*. This Anaplasma is transmitted by ticks, and it is a noteworthy fact that the incubation time by tick transmission is much longer than that after inoculation of the animal with blood; in the experiments carried out it varied from 55 to 75 days. Blood of an immune animal is infective; such an animal forms the reservoir of the virus. This is a peculiarity of the piroplasma diseases to which group *Anaplasmasis* also belongs. Dr. Theiler's opinion is that Anaplasmasis is probably the disease which the farmer has hitherto called "Gall Sickness." Up to the present four different parasites are, in South Africa, found in the blood of immune cattle, and they can all be transmitted by the inoculation of the blood and by ticks.

"On the Development of *Piroplasma parvum* (*Protozoa*) in the Various Organs of Cattle" by Dr. R. GONDER. The author suggests an explanation of the fact that the blood of animals suffering from East Coast fever injected into healthy animals does not transmit the disease. It is possible he thinks, that the blood containsf orms which can develop in the tick,

and which, when injected, die. Concerning the place of the East Coast fever parasite in protozoology, he thinks the proposition justifiable to separate it from *Piroplasma*, and to substitute a new generic name "*Theileria*," as suggested by Bettencourt.

ORDINARY MONTHLY MEETING.

July 20, 1910.

The President, S. S. HOUGH, Esq., F.R.S., in the Chair.

The President announced that Rev. E. GOETZ and H. G. FOURCADE were recommended to the Society for election as Ordinary Fellows; and that they have put in nomination for election as Honorary Fellow, Sir WALTER HELY-HUTCHINSON.

Miss BLEEK, Messrs. P. J. DU TOIT, and Dr. F. ENGELENBURG were nominated for Ordinary Membership.

"Factorizable Continuants," by THOMAS MUIR, LL.D. A short paper with the above title was presented to the Society more than six years ago, and appears in the *Transactions*, vol. xv., pp. 29–33. Attention has now to be drawn to the fact that the fundamental theorem of this paper has by some oversight just been published as a fresh discovery of Professor METZLER's in the British Association Report (Winnipeg Meeting), p. 390. The identity of the two results is seen on changing the letters n, a, b, c of the earlier paper into $n+1$, r, aa, $a(\beta-a)$.

"The Effect of the Electric Discharge on Water Vapour," by E. JACOT. Experiments leading to results not in agreement with those of M. Henry (*Journal de Physique*, Jan., 1909, pp. 33–38), viz.: that cathode rays are produced in vacuum tubes containing water vapour at pressures higher than is the case in tubes containing air. The electric discharge brings about reduction of the vapour. In tubes containing metallic electrodes, the reduction, if started by the passage of a discharge, will even proceed quite independently of the discharge. In electrodeless tubes the final steady state of pressure of electrolytic gas depends on the pressure under which the water vapour is initially admitted, and is affected by the presence of colouration on the glass due to chemical action by cathode rays.

Note on "Verneuk Pan," by A. W. ROGERS, Sc.D. Verneuk Pan is a flat surface cut in shale and partly covered with sandy mud which forms a thin layer only. It is a striking example, being over 100 square miles in area, of numerous pans on the Dwyka formation in the north of the Colony. It has an outlet over a bar of hard dolerite. The formation of this and other pans which lie in the course of streams was probably due in

the first place to the extremely low grade reached by streams behind bars of hard rock, then to the unfavourable conditions for plant-growth owing to the increasing brakness of the soil, which is due to the lack of sufficient surface drainage, and the scope thus given to the wind to remove dust and sand from the bare ground.

"A Further Note on the Diurnal Variation of Level at Kimberley," by Dr. J. R. Sutton. The suggestion is made that the diurnal oscillation of level may be of photo-electric origin. Experiments made to test the idea are so far not very definite. Meteorological results at Kimberley are not in disagreement with some kind of photo-electric theory. The extreme range of the pendulum from west to east is greatest on clear days, and least on very cloudy days. Also the range of earth temperature is greater or less according as the sky is clear or cloudy. When the barometer is lowest during the passage of a barometric depression the diurnal range of the pendulum diminishes to a minimum, and rises to a maximum as the depression passes away. The clouds which form in the depression are responsible for a large part of the variation of level indicated by the range of the pendulum.

Dr. L. Péringuey gave an account of recent finds made in rock-shelters once occupied by Strand Loopers (a branch of the Hottentot race) and exhibited the relics obtained. These imply a simple culture, remains of which were little or not known hitherto. But that culture was not limited to these troglodytes. Nor were these aborigines cantoned only in caves. A comparison of the scenes painted on stone implements, such as a quern, and on flat slabs found under a considerable depth of kitchen refuse, showed certain peculiarities to be met with only in paintings occurring in localities far removed from these cave-shelters. The figure of a giraffe in an open-air painted scene, not far removed from the shelters, as well as two teeth of crocodile, clearly pointed to wanderings in the interior of the Colony on the part of the dwellers. The giraffe could not have existed in that part of the country, and was represented therefore from memory; and the crocodile was certainly no longer a denizen of these parts. Either the climatic circumstances had greatly changed—and this would postulate a great antiquity for the cave-dwellers—or, what is more likely, these cave-dwellers were great rovers. The author laid great stress on the help which careful examination and comparison of the Bush paintings afford. Having gone into details as to the mode of sepulture and the position which the body was made to assume, he exhibited a fragment of stone with bush paintings found in one of the caves, representing four natives in almost the same position as that in which the skeletons were found. Moreover, over these skeletons had been placed two or three flat stones, some of which bore traces of fire. This mode of sepulture had not been authenticated hereto.

ORDINARY MONTHLY MEETING.

August 17, 1910.

The President, S. S. HOUGH, Esq., F.R.S., in the Chair.

Dr. E. J. GODDARD, Dr. M. PARK, and M. M. WESSELS were nominated for ordinary membership.

P. J. DU TOIT, Dr. F. ENGELENBURG, and Miss D. BLEEK were elected ordinary members.

The Secretary, Dr. PÉRINGUEY, exhibited some flat slabs, artificially polished, and discovered in Strand-Looper-Hottentot sepultures. It was thought at first that these flat lamellæ were braying implements, and, of course, they might, for that matter, have also been used effectively as such. But another example was brought to his notice which shows conclusively that their purpose was of a different nature. It was found in a rock-shelter and is covered on one side with a red pigment (oxide of iron) mixed with a fatty substance. It is not, however, a "palette" in its true sense, but an implement used to besmear the body. The interest attaching to these palettes is that in shape, thickness, &c., they resemble similar utensils found in the Dolmens of Southern France (Aveyron) as well as in Egyptian tombs.

"The Influence of Uniformity and Contrast on the Amount of Light Required," by H. BOHLE. The author dealt first with the adaptability of the human eye to various daylight illuminations, and gave a new definition of glare: When the eye looks at an illuminant of great intrinsic brilliancy in front of a dark background it tries to do two things at once: To open wide for the dark background and to close up for the intrinsic brilliancy. The author then considered the physiological effects of radiation, explained overheating of the eyes due to excess of light absorption and considered the effects of the ultra-violet rays of modern illuminants and of solar radiation. In addition he treated the effects of light radiation on germs of disease, the destructive action of rays when applied excessively, and finally dealt with the effect which uniformity and the avoidance of contrast in artificial lighting have on the amount of light required. He came to the conclusion that in a room with black walls an illumination of 35 to 40 candle-metres were required, whereas in a place with white ceilings and light walls the amount of light could be reduced to 30 candle-metres. For perfect uniformity in such places, as obtained with inverted lamps, 20 candle-metres give, in the opinion of the author, complete satisfaction. The effects of various lamp shades on the uniformity of illumination were also shown.

ANNUAL MEETING.

September 28, 1910.

The Vice-President, Professor H. H. W. PEARSON, in the Chair.

Mr. H. G. FOURCADE and the Rev. E. GOETZ were elected Fellows of the Society.

After the Election the Meeting resolved into an Ordinary Meeting.

The Vice-President recommended the election of the Right Hon. Baron DE VILLIERS as a Fellow of the Royal Society, " whose election will be of signal benefit to the Society." This election would take place according to the Statutes, Ch. I. XIII.

Dr. E. J. GODDARD, Dr. M. PARK, and Mr. M. M. WESSELS were elected Ordinary Members of the Society.

Messrs. D. T. MITCHELL, M.R.C.V.S., W. H. ANDREWS, B.Sc., M.R.C.V.S., D. KEHOE, M.R.C.V.S., and Dr. WOOD were nominated for Ordinary Membership.

ORDINARY MONTHLY MEETING.

October 19, 1910.

The President, S. S. HOUGH, Esq., F.R.S., in the Chair.

Lord DE VILLIERS ρf Wynberg was elected a Fellow of the Society.

Messrs. D. T. MITCHELL, W. H. ANDREWS, D. KEHOE and Dr. WOOD were elected Ordinary Members.

" An Investigation into the Land and Sea Breezes Conditions at Port Elizabeth," by A. G. HOWARD, M.S.A. This is a second contribution to the Meteorology of South Africa.

A paper was read by Mr. E. T. LITTLEWOOD, M.A., B.Sc., on " Graphical Representation of Some of the Simpler Analytic Functions of a Complex Variable," illustrated by models and diagrams. The modulus of the function corresponding to each point of the (horizontal) xy plane was represented by the length of a vertical line erected at that point, the upper extremities of these lines forming a (" modular ") surface, while the argument was represented by a family of curves (" stream lines ") drawn in the xy plane. Certain general results were established and methods given.

In the models, the surface was suggested by a wire frame-work, which usually illustrated contour lines and vertical sections, while the stream lines, drawn on the horizontal base of the model, were visible through the framework. The simpler algebraic, circular, exponential and logarithmic functions were thus treated.

LIST OF FELLOWS AND MEMBERS.

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FELLOWS.

Anderson, A. J., *M.A.*, *M.B.*, Town House, Cape Town.

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Behr, H. C., P.O. Box 1167, Johannesburg.

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Corstorphine, G. S., *B.Sc.*, *Ph.D.*, P.O. Box 1167, Johannesburg.

Crawford, L., *M.A.*, *D.Sc.*, South African College, Cape Town.

Gilchrist, J. D. F., *M.A.*, *B.Sc.*, *Ph.D.*, South African Museum, Cape Town.

Goetz, *Rev.* E., *S.J.*, The Observatory, Bulawayo.

Hahn, P. D., *Ph.D.*, South African College, Cape Town.

Hall, A. L., *B.A.*, Geological Survey, Pretoria.

Halm, J. K. E., *Ph.D.*, Royal Observatory, C. C.

Hough, S. S., *M.A.*, *F.R.S.*, Royal Observatory, C. C.

Innes, R. T. A., *F.R.A.S.*, Meteorological Department, Johannesburg.

Ingle, H., 33, City Road, Birmingham.

Kynaston, H., *B.A.*, *F.G.S.*, Geological Survey, Pretoria.

Lehfeldt, R. A., *B.A.*, *D.Sc.*, Transvaal University College, Johannesburg.

Lounsbury, C. P., *B.Sc.*, Department of Agriculture, Cape Town.

Marloth, R., *Ph.D.*, *M.A.*, Church Street, Cape Town.

Mellor, E. T., *D.Sc.*, Geological Survey, Pretoria.

Moir, J., *M.A.*, *D.Sc.*, Mines Department, Johannesburg.

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Ogg, A., *M.A.*, *B.Sc.*, *Ph.D.*, Rhodes University College, Graham's Town.
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Péringuey, L., *D.Sc.*, *F.E.S.*, *F.Z.S.*, South African Museum, Cape Town.
Purcell, W. F., *B.A.*, *Ph.D.*, South African Museum, Cape Town.
Reunert, T., *M.I.C.E.*, P.O. Box 92, Johannesburg.
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Schönland, S., *M.A.*, *Ph.D.*, Albany Museum, Graham's Town.
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Dru-Drury, E. G., *M.D.*, *BSc.*, High Street, Graham's Town, C. C.
Duerden, J. E., *Ph.D.*, Rhodes University College, Graham's Town.
Duthie, Miss A. V., *B.A.*, Victoria College, Stellenbosch, C. C.
Engelenburg, F. W., *Ph.D.*, Offices of the *Volkstem*, Pretoria.
Evans, M. S., *F.Z.S.*, Durban, Natal.
Eyles, F., Mazoe, Rhodesia.
Fairbridge, W. G., 141, Longmarket Street, Cape Town.
Feltham, H. L. L., P.O. Box 46, Johannesburg.
Fincham, C. H. H., *M.A.*, Hopewell, Imvani, C. C.
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Fourcade, H. G., Stornes River, C. C.
French, G., Public School, Claremont.
Fry, Harold A., P.O. Box 46, Johannesburg.
Fuller, C., *F.E.S.*, Agricultural Department, Maritzburg.
Fuller, E. Barnard, *M.D.*, Church Square, Cape Town.
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Goddard, E. J., *D.Sc.*, Victoria College, Stellenbosch, C. C.
Gray, Chas. J., Department of Mines, Maritzburg.
Grimmer, I. R., De Beers, Kimberley.
Guest, A. M., Klerksdorp, Transvaal.
Gunning, J. W. B., *Ph.D.*, Museum, Pretoria.
Haarhoff, D. J., *M.L.A.*, Kimberley.
Haffe, J. A., *A.M.I.C.E.*, P.O. Box 1401, Cape Town.
Harger, H. S., P.O. Box 1945, Johannesburg.
Hayward, S. H., Hofmeyer Chambers, Cape Town.
Henkel, J. S., Forest Department, Knysna, C. C.
Henderson, J. McLelland, *Ph.D.*, Johannesburg.
Hewitt, J., *B.A.*, Museum, Graham's Town.
Howard, C. W., *B.A.*, P.O. Box 25, Lourenço Marques.
Howard, R. N., *M.R.C.S.*, O'okiep, C. C.
Humphrey, W. A., *B.A.*, *Ph.D.*, *F.G.S.*, Geological Survey, Pretoria.
Jagger, J. W., *F.R.S.S.*, *M.L.A.*, St. George's Street, Cape Town.
Janisch, N., Colonial Office, Cape Town
Janse, A. J. T., Normal College, Pretoria.
Jardine, W., Cape Town.
Jorissen, E., *Ph.D.*, P.O. Box 305, Johannesburg.
Juritz, C. F., *D.Sc.*, Government Laboratory, Cape Town.
Kanthack, T. E., *A.M.I.C.E.*, Public Works Department, Cape Town.
Kehoe, D., *M.R.C.V.S.*, Department of Agriculture, Pretoria.
Kensit, Miss H. M. L., *B.A.*, Sherwood, Kenilworth.
Kilpin, E. F., *C.M.G.*, Houses of Parliament, Cape Town.
Kirkman, A. H., *F.R.C.S.E.*, Touws River, C. C.
Kitching, C. McGowan, *M.D.*, Church Street, Cape Town.
Knobel, J. C. J., Tokai, Cape Town.
Kolbe, *Rev.* F. C., *B.A.*, *D.D.*, St. Mary's Presbytery, Cape Town.
Krapohl, J. H. C., *B.A.*, Concordia, C. C.
Lawrence, F. J., Steytlerville, C. C.
Leslie, T. N., Vereeniging, Transvaal.
Leviseur, M., Bloemfontein.
Lightfoot, R. M., *F.E.S.*, Museum, Cape Town.
Lindley, J. B., *C.M.G.*, *M.A.*, *LL.B.*, Claremont, C. C.
Logeman, W. H., *M.A.*, South African College, Cape Town, C. C.
Lotz, H., *Ph.D.*, Berlin.
Louw, A. J., *B.A.*, *B.Sc.*, Heidelberg, Transvaal.
Lyle, J., *M.A.*, Grey College, Bloemfontein, O. R. C.
Maberly, J., *M.R.C.S.*, Woodstock, C. C.
MacLean, L., Union Castle Company, Cape Town.
Macmillan, B. R., Cape Town.
Mallison, P. R., Hex River, C. C.
Mally, C. W., *M.Sc.*, Graham's Town, C. C.
Mann, G., South African Association, Cape Town.
Manseregh, C. L. W., Public Works Department, Cape Town.
Marshall, G. A. K., *F.E.S.*, *F.Z.S.*, 6, Chester Place, London.
Masson, J. L., Surveyor-General's Office, Maritzburg.
Maxfield, J. W., *A.R.C.S.*, Victoria College, Stellenbosch.
Meiring, I. P. Van H., Worcester, C. C.
Melvill, E. H. E., Johannesburg.
Mendelssohn, S., Kensington Court Gardens, London.
Menmuir, R. W., *A.M.I.C.E.*, Woodstock, C. C.
Millar, A. D., Durban, Natal.
Milligan, A., Durban, Natal.
Mitchell, D. T., *M.R.C.V.S.*, Department of Agriculture, Pretoria.
Moffatt, J. B., Kenilworth, C.C.
Molengraff, G. A. F., *Ph.D.*, P.O. Box 149, Johannesburg.
Muirhead, J. M. P., *F.S.S.*, Selwyn Chambers, St. George's Street, Cape Town.
Muller, A. H. T., Johannesburg.
Nobbs, E., *Ph.D.*, Department of Agriculture, Salisbury, Rhodesia.

O'Connor, E. J., Forest Department, Mowbray, C. C.
Oppenheimer, E., P.O. Box 273, Kimberley.
Orpen, J. M., Durban, Natal.
Park, M. H., *M.A.*, *L.L.D.*, Cape Town C. C.
Phillips, E. P., *M.A.*, Museum, Cape Town.
Pickstone, H. E. V., Groot Drakenstein, Paarl.
Pillans, N. S., Rosebank, C. C.
Pöch, R., *M.D.*, Vienna.
Pole-Evans, I. B., *B.Sc.*, Department of Agriculture, Pretoria.
Potts, G., *B.Sc.*, *Ph.D.*, Bloemfontein.
Proctor, J., Mafeking, C. C.
Queckett, J. F., *F.Z.S.*, The Museum, Durban, Natal.
van der Riet, B., *Ph.D.*, *M.A*, Victoria College, Stellenbosch, C. C.
Ritchie, W., *M.A.*, South African College, Cape Town.
Rix-Trott, H., Poste Restante, New Zealand.
Rose, J. G., Agricultural Department, Cape Town.
Russell, W. A., *M.A.*, Education Department, Cape Town.
Ryan, P., Rosebank, C. C. .
Schreiner, *Hon.* W. P., *K.C.*, Lyndale, Newlands, C. C.
Sclater, W. L., *M.A.*, *F.Z.S.*, 10, Sloane Court, London.
Sheppard, P. A., Beira.
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Smith, F. B., *B.A.*, Secretary for Agriculture, Pretoria.
Snape, A. E., *A.M.I.C.E.*, South African College, Cape Town, C.C.
Stewart, C. B., *B.Sc.*, Meteorological Department, Cape Town.
Stewart, T., *F.G.S.*, *M.I.C.E.*, St. George's Street, Cape Town.
Stoney, W. W., *M.D.*, Kimberley, C. C.
Stott, C. H., *F.G.S.*, Pietermaritzburg, Natal.
Swierstra, C. J., Transvaal Museum, Pretoria.
Taylor, L. E., Irene, Transvaal.
Tennant, David, Burg Street Chambers, Cape Town.
Thompson, W. Wardlaw, *F.Z.S.*, Cape Town.
Tooke, W. Hammond, Graham's Town.
Toit, P. J. du, Agricult. Dept., Pretoria.
Tredgold, C. F., *B.A.*, *LL.B.*, P.O. Box 306, Bulawayo.
Tregarthen, W. Coulson, Queen's Town, C. C.
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de Villiers, The *Lord*, *K.C.M.G.*, *P.C.*, Wynberg, C. C.
Walker, A. R. E., *B.Sc.*, *A.R.C.S.*, The Museum, Cape Town.
Wallis, A. H., Mafeking, C. C.
Walsh, A., P.O. Box 39, Cape Town.
Weber, F. W., *M.D.*, Paarl, C. C.
Wessels, M. C., *F.R.G.S.*, "Miramar," Green Point, Cape Town, C. C.
Whaits, *Rev.* J. H., The Rectory, Laingsburg.
White, Franklin, Bulawayo.
Williams, A. T., *B.Sc.*, De Beers, Kimberley.
Willman, (Miss) M., Museum, Kimberley.
Wood, D. J., *M.B.*, *C.M.*, Cape Town, C. C.
Wood, J. Medley, Berea, Durban.
Young, A., *M.A.*, *B.Sc.*, South African College, Cape Town.
Young, R. B., *M.A.*, *B.Sc.*, Technical Institute, Johannesburg.
Zealley, A. E. V., *A.R.C.S.*, Rhodesia Museum, Bulawayo.

MINUTES OF PROCEEDINGS

OF THE

ROYAL SOCIETY OF SOUTH AFRICA.

ORDINARY MONTHLY MEETING.

March 15, 1911.

The Vice-President, Dr. H. H. W. PEARSON, in the Chair.

Nominations:—

F. T. E. DREYER, M.A., Ph.D., Cape Town, by C. LOUNSBURY and C. K. BRAIN; Sir KENDAL FRANKS, Johannesburg, by J. MOIR and R. T. A. INNES; J. DE FENTON, Johannesburg, by R. T. A. INNES and J. MOIR; A. D. LEWIS, Cape Town, by L. PÉRINGUEY and R. M. LIGHTFOOT; The Hon. P. METHUEN, Pretoria, by J. W. B. GUNNING and C. J. SWIERSTRA; Rev. N. ROBERTS, Rietfontein, by J. W. B. GUNNING and C. J. SWIERSTRA; H. E. WOOD, M.Sc., Johannesburg, by R. T. A. INNES and L. PÉRINGUEY; E. H. L. GORGES, by S. S. HOUGH and L. PÉRINGUEY; Hon. J. C. SMUTS, by S. S. HOUGH and L. PÉRINGUEY; C. L. LEGAT, by A. THEILER and W. H. ANDREWS; W. A. TUCKER, by L. PÉRINGUEY and J. C. BEATTIE.

The Vice-President gave notice that the Anniversary Meeting for the election of Council and officers would be held on April 19, 1911.

Communications:—

"Sylvester's and other Unisignants," by Dr. THOS. MUIR.

Unisignant is the name given to a peculiar class of multilinear functions which though expressible as determinants are quite unlike the latter functions in their properties, having, for example, in their final development nothing but positive terms. Probably the first instance of such a function was observed by Sylvester. The object of the present

paper is to throw fresh light on Sylvester's work by bringing it into the same field of view with certain recent investigations of a more general character about to appear in the *Quarterly Journal of Mathematics.*

"Upon the Fourth Order Perturbations in the Motions of Satellites III. and IV. of Jupiter," by R. T. A. INNES.

The author recomputes and practically confirms the values of certain long-period inequalities in the longitude of the third great satellite of Jupiter originally discovered by the late M. de Haerdtl. These inequalities are due to the near approach of commensurability of the mean motions of the III. and IV. satellites; seven times the mean motion of IV. being nearly equal to three times that of III., so that although these inequalities depend on the fourth powers of the eccentricities they exceed the limit of II. adopted in Professor Sampson's "New Tables of the Great Satellites of Jupiter, 1910." The inequalities in the motion of IV. are now computed for the first time. In the sum these inequalities will at times amount to about 8″ in the longitude of III. and 10″ in that of IV.

"The Funeral Ceremonies of the Hottentots," by C. L. BIDEN and G. KLING.

The Hottentots have their medical-men who treat patients during illness. Like most South African tribes, witchcraft is practised by these medicine-men, and the sick are told that their enemies, bad relatives, and bad neighbours are the cause of illness. In the event of death following, the medicine-man attributes the disaster to the bad influence of certain parties, actually naming the persons he thinks concerned. Formerly these responsible persons were put to death; now it leads to much hatred and personal feeling among the Hottentots. Immediately after death they prepare for the funeral. A grave is dug by means of a Gemsbok horn and a roughly made wooden shovel. The ceremonial is then described. After the funeral a dance is held, and festivities are indulged in, all through the night. For a few weeks the male relatives of the deceased go to the grave every morning before sunrise, quite naked, and pray to the "taas" (ghost). After that time they suppose that the ghost has left the grave and has entered an animal called by them "taas" jackal. This animal they assert has never been caught, and it can only be killed by a silver bullet.

"The Meteorites in the Bloemfontein Museum," by W. A. D. RUDGE.

The paper contains an account of the meteorites in the Bloemfontein Museum. There are two fragments of the Kroonstadt fall of 1877. These apparently consist of a tough fibrous mass of iron-nickel alloy, with an aggregation round it of fine particles of silica (asmanite ?), troilite pyrites, and apparently felspar. The larger meteorite which fell at Winburg, 1881, contains 94 per cent. of iron and 2 per cent. of nickel.

The nickel is confined to a few veins which run through the mass of the meteorite. From these veins crystals of the alloys can be separated by dilute sulphuric acid, in which the alloy is insoluble. These crystals seem to be skeleton forms built up of triangular plates, the interstices being filled up with amorphous carbon. The iron is very soft, but patches of hardness occur. The "Widmanstatten" lines are not so well developed as in most iron meteorites, probably due to the nickel being located in veins instead of disseminated throughout the whole mass. The weight of this meteorite was about 50 kilogrammes, and it is markedly magnetic, having a number of poles. The alloy of nickel and iron retains its susceptibility up to a dull red heat.

"Seismographic Record of the South African Earthquake of October, 1910," by J. R. Sutton.

The extent of the movement of the horizontal pendulum during the quake was about one-half its average daily E.W. oscillation.

"Colloidal Gold and Purple of Cassius," by JAMES MOIR.

Description of behaviour of chloroauric acid dissolved in 200,000 parts of water towards a number of reducing agents. The colouration produced by pure stannous chloride, $SnCl_2$, is not purple of Cassius but a brown of remarkable stability, which the author shows is not due to extreme fineness of division, and which may be colloidal aurous chloride. Purple of Cassius results when $SnCl_2$ and an oxidant with loosely bound oxygen are employed. The tin in the purple is shown to be merely a vehicle for finely divided gold, the shade varying from pink to indigo according to the rapidity of formation, the first division being obtained by the slow reducing action of glycerol.

"Some Remarkable Oxidation Products of Benzidine," by JAMES MOIR.

An investigation of the beautiful blue products obtained from benzidine by certain processes of oxidation, such as the blood test. The products obtained by the action of chromic acid and of ferricyanide are shown to be the chromate and ferricyanide respectively of diphenoquinone-diimine $NH : C_6H_4 : C_6H_4 : NH$, but the latter is an extremely reactive substance and polymerises easily to very insoluble substances of the aminoazo-dye class. Benzidine is the sole reduction-product of the blue substances as freshly prepared. The violet azo-dye appears to be $NH_2 \cdot C_{12}H_8 \cdot N : N \cdot C_{12}H_8 \cdot NH_2$.

"The Egyptian Influence on Rhodesia Ruin Builders, or Vice Versa," by H. W. TARBUTT.

The object of this note is to show that MacIver's statement that the Rhodesian ruins are of native origin does not seem too improbable, if the articles found in or about the Rhodesian ruins are compared with similar articles of Egyptian primitive art. The author contends

that the very resemblance between them is not confined to one or two articles, but to almost everything that has been found, and illustrations comparing the Rhodesian and Egyptian objects are given to support the theory.

ANNIVERSARY MEETING.

April 19, 1911.

The President, S. S. HOUGH, F.R.S., in the Chair.

The Reports of the Secretary and Treasurer were read and approved.

The Council for the ensuing year was elected as follows :—

President : S. S. HOUGH, M.A., F.R.S.

Hon. Treasurer : L. CRAWFORD, D.Sc.

Hon. Secretary : L. PÉRINGUEY, D.Sc.

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The PRESIDENT delivered his Address, "Photography an Aid to Astronomy."

ORDINARY MONTHLY MEETING.

May 19, 1911.

The Vice-President, S. S. HOUGH, Esq., F.R.S., in the Chair.

Nominations : J. E. DEVLIN, Uitenhage, by L. PÉRINGUEY and R. M. LIGHTFOOT ; Dr. SIMPSON-WELLS, F.R.C.S., by J. D. F. GILCHRIST and L. PÉRINGUEY.

Elections : J. F. DREYER ; J. DE FENTON ; Sir KENDAL FRANKS ; E. H. L. GORGES ; C. L. LEGAT ; A. D. LEWIS ; Hon. P. METHUEN ; Rev. N. ROBERTS ; Hon. J. C. SMUTS ; W. TUCKER ; H. A. WAGER ; H. E. WOOD.

The PRESIDENT nominated as Vice-Presidents H. H. W. PEARSON, Sc.D., and R. T. A. INNES, F.R.A.S.

"Some New South African Succulents and other Plants," by R. MARLOTH.

Among the plants described in this paper are three species of special interest, viz., one of *Cytinus*, one of *Borbonia*, and one of *Anacampseros*. The Cytinus is noteworthy as it constitutes a second species of Rafflesiaceæ for South Africa ; the Borbonia is of economic importance, being

the source of a colonial tea, viz., "rooibosch-tea," and the Anacampseros is another example of mimicry-plant, of which eight species were described in previous papers.

"Note on the Language of Bushmen Tribes North of the Orange River," by Miss D. L. BLEEK.

All words and sentences taken down from Bushmen south of the Orange River show that they spoke one language, with dialectical variations. North of the Orange River, however, in the Langeberg and adjoining Southern Kalahari, we find a different language, that of II n Bushmen, closely allied to that of I Xam Bushmen (those south of the river); the difference in the vocabulary and still more in the grammar of these two tribes is too great to be called a mere dialectical variation. In the Northern Kalahari the so-called Basarwa are found, people living exactly as Bushmen do, though said to be mixed in type. The South African Museum has a series of gramophone records taken from pure Basarwa, in the heart of the Kalahari region, which the author has transcribed, and which, in spite of the instrument not having recorded clicks, clearly gave valuable evidence that the language belongs to the Bushman family. For Bushmen distinguish between words of apparent identical sound, by the tone in which they are spoken, sometimes speaking quite low and roughly in their throats, sometimes on a high note; again, some words have a rising, others a falling accent. Occasionally one word is spoken with a musical intonation, sung as it were in the middle of a spoken sentence. All these peculiarities the gramophone reproduces, showing the likeness of Basarwa, in this feature at least, to the I Xam and II n tongues.

"Note on the Result of Investigation of a Strand Looper Rock-shelter, with Exhibition of the Objects found," by L. PÉRINGUEY.

The cave which it was decided to excavate is, properly speaking, a rock-shelter, filled with an accumulation of kitchen refuge, blown sand, &c. The excavation was carried through a depth of nearly 14 feet of this material, when it was found necessary to stop, owing to the dampness of the detritus. The cave was originally discovered by Mr. C. J. Whitcher, who carried on some excavation first, and very kindly allowed the Museum to proceed with further exploration work. This cave proves to have been a necropolis; a considerable number of skeletons having been found at different depths. In the pelvic bone of a young child (female) was found embedded a small stone chip, part of the point of an arrow, probably poisoned. Most of the skeletons are in a greatly advanced stage of decay. Some are plainly Strand Loopers, but others were found which are not Strand Loopers; they are of greater and more robust stature, and would appear to be half-bred, or perhaps Kaffirs, yet the mode of burial is the same, but the skulls of this "larger race" are not entire, nor could all the

fragments be found. A feature of the hitherto unrecorded burial rites is the placing of flat stones, occasionally painted, on the hunched-up body resting on its side. One of these stones has polychrome paintings of the Bushman type, but, unlike any of these paintings, in this one the eye and an attempt at facial delineation is noticeable. The evidence of the bone and stone implements found in this sepulture not only indicates that the two industries prevailed simultaneously, but also that implements of palæolithic and neolithic type were coeval. It can now be said that in South Africa the hiatus which in Europe, or in the Palæarctic Regions, separates the palæolithic from the neolithic, is now proved not to have existed.

"Observations on the Inheritance of Character in Zea Mays, L.," by T. BURTT-DAVY.

I. In Red Cuzco, and some other breeds of red maize, the red colouring matter is confined to the pericarp, and is therefore a fruit character; it does not appear in the first cross between a white male and a red female. In a "red dent" breed the red pigment occurs in the aleurone layer; it is therefore a seed character; it is dominant to whiteness. When this breed is crossed with a "white sugar" breed the results in the second generation are approximately:—

Red: Starchy, 56·25 per cent.; Sugary, 18·75 per cent. = 75 per cent.
White: Starchy, 18·75 per cent.; Sugary, 6·25 per cent. = 25 per cent.

A single grain has been seen, in which the starchy character appears in one half, the sugary character in the other.

II. The number of rows on a maize ear, within certain limits, is subject to fluctuating variations, which may perhaps be affected by season or food supply, or both.

III. When an 8-row type is crossed with an 18-row type, both characters disappear in the heterozygous form, and an intermediate type is produced, in which there are 10, 12, or 14 rows, 12 rows greatly predominating.

IV. A white-cobbed breed crossed with a red-cobbed produces a red-cob in the first filial generation. Result of reciprocal cross is the same.

"On the Early Babylonian Eclipses of the Sun," by E. NEVILL.

On the fourteenth line of Tablet No. 35968 of the British Museum Collection, Mr. King has deciphered the record:—

"On the twenty-sixth day of the month Sivan in the seventh year the day was turned into night and fire in the midst of heaven. . . ."

From collateral evidence contained on the tablet the author supports Mr. King's contention that the phenomenon referred to is a total eclipse of the sun, but differs from Dr. Cowell, who has identified it with the eclipse of B.C. 1062, July 31st. The author has examined the features

of some seventy eclipses which occurred between B.C. 1250 and B.C. 950, the extreme limits of date which seem to be compatible with the inscription, and finds that three of these only appear to satisfy the prescribed conditions of having been visible from the neighbourhood of Babylon at a time of year corresponding with the twenty-sixth day of the month Sivan, viz., those of —1217 June 5th, —1123 May 18th, and —956 May 31st. The identification of this eclipse is of importance as bearing on the theory of the moon's motion, as well as in relation to doubtful points concerning the chronology of the earlier kings of Babylon.

"Sylvester's Axisymmetric Unisignants," by T. MUIR.

ORDINARY MONTHLY MEETING.

June 21, 1911.

Dr. MARIUS WILSON in the Chair.

Nominations: R. D. MCLEISH, Kimberley, by J. R. SUTTON and L. PÉRINGUEY.

Elections: J. E. DEVLIN; Dr. SIMPSON-WELLS.

"A Note on the Principal Systematic Work and Publications dealing with the South African Proteaceæ," by E. P. Phillips.

The first recorded publication of a member of this order was by Clusius in 1605. In 1720 Boerhaave attempted a systematic study of the order, but it was not until 1809 that a really scientific monograph was published by Salisbury; in the following year appeared the classic work of Robert Brown. The standard work on the order is a monograph by Dr. Meisner, which appeared in De Candolle's Prodromus in 1856, where 279 species are described. The writer undertook to revise the order, and has recorded between 300 and 400 species. The genera *Diastella*, Salisb., and *Orothamnus*, Pappe, sunk by Meisner, have been re-established, and one new genus, *Spatallopsis*, Phillips, founded.

"The Spectrum of the Ruby," Part II., and the "Artificial Ruby," by J. MOIR.

By examination of the ruby with better instruments, the complete spectrum of 8 hair lines has been discovered; they are best seen in the artificial ruby, which is identical with the natural ruby in all respects, and when free from flaws is actually superior to the natural gem.

"Notes on the Spectrum of the Precious Emerald, and other Gem Stones," by J. MOIR.

The emerald spectrum contains three very difficult hair lines in the red. Sapphires have no hair lines in their spectrum. Artificial emeralds are green sapphires, and have an indefinite spectrum, as is also the case

with the following: Rubellite, Spinel, Amethyst, Fluor, Aquamarine, Rose-quartz, Lepidolite, and Topaz. The Almandine spectrum has been re-examined.

"A note on the Land and Sea Breezes of South Africa," by J. R. Sutton.

Ordinary Monthly Meeting.

July 19, 1911.

The President, S. S. Hough, Esq, F.R.S., in the Chair.

Nominations: R. H. Greaves, Willowmore, by H. Brauns and L. Péringuey; Professor F. H. Le Roux, Pretoria, by L. Péringuey and L. Crawford.

Elections: R. D. McLeish; E. C. Chubb.

The President read the names of candidates selected by the Council for election as Fellows. The election will take place on the third Wednesday in September.

The following motion was carried: "That the Royal Society of South Africa desires to record its deep sense of the loss which South African Science has suffered in the death of Dr. Harry Bolus, a Fellow of the Society, and to express its sympathy with the members of his family in their bereavement."

Communications: "Terrestrial Isomagnetic Lines in South Africa," by J. C. Beattie.

Ordinary Monthly Meeting.

August 16, 1911.

The President, S. S. Hough, Esq., F.R.S., in the Chair.

Elections: R. H. Gréaves and F. H. le Roux.

Exhibition: Dr. L. Péringuey exhibited a miniature quiver, bow and arrows, made by the Basarwa Bush people living in the centre of the Kalahari. The bow, made of horn, is barely 5 inches long, and the arrows, for which sharp thorns are used, are small in proportion, and coated with what is supposed to be a most virulent poison, the antidote for which is unknown. According to Mr. Kirkham, who presented these extremely interesting specimens, very difficult indeed to procure, these miniature arms are real Bushman weapons, and as far as he has been able to gather only used by them for the settlement of love quarrels, the bow being used at night-time, when the rival is taking part in a dance, generally held when the moon is at or near full,

"A Note on the Heije Eibib, or Stone Mound of Namaqualand," by L. PÉRINGUEY.

The name Heije Eibib is usually given to artificial mounds of stone occurring in certain places in Namaqualand and elsewhere, the formation of which is ascribed to the Hottentots, who, whenever passing the spot, add a stone to the cairn, taking great care, however, that in so doing their shadow be not projected on the mound. But so far there was nothing to prove that these cairns were really a kind of sepulture. Lately, however, one such mound was opened and it was found that the accumulation of stones covered parts of a body; the skull is, to all appearances, that of a Bush. But Rev. Kling informs the writer that there are two kinds of Heije Eibib. The one opened is known as Heije Eibib Garedje, and would be the grave of a Bush witch-doctor, erected by his people. But it is not yet proved that the Hottentot's Heije Eibib is a grave.

"On the Secular Acceleration of the Orbital Motion of the Moon," by E. NEVILL.

The paper begins with a critical examination of the records of the principal ancient eclipses of the sun mentioned as being total, or very nearly total, by different Assyrian, Babylonian, Grecian, and Chinese records. The exact conditions of each eclipse have been calculated from the best modern theoretical data according to Hansen's method of computation. As a result it is shown that with our present knowledge it is not possible by any system of data consistent with the modern observations of the sun and moon to bring all the principal eclipses recorded by ancient authorities as having been total into accord with the tables. The second portion of the paper assumes the existence of a secular acceleration in the motion of the earth around the sun, and proceeds to consider what might be the origin, and to what degree the existence of this cause will modify the motion of the different members of the solar system, and how far the deduced consequences are in harmony with observation. It is shown that the case of the terrestrial tidal effect due to the action of the sun and moon does not form a conservative system and that the principle of conservation of angular momentum does not hold for any non-conservative system of forces. No other origin for a secular acceleration being apparent, the great difficulty in reconciling the consequences of such a secular acceleration with the known motion of the sun and moon renders it preferable to look to one of the other permissible causes as a means of reconciling the existing theories of the sun and moon with the records of the ancient eclipses of the sun and moon.

"Some Observations concerning the Transmission of East Coast Fever by Ticks," by A. THEILER.

In the experiments it has been proved :—

(1) That brown tick imago which as larvæ had become infected with

East Coast fever and which had transmitted the disease in their nymphal stage, were no longer infective for susceptible cattle. Four batches of ticks proved their infectivity in the nymphal stage on eight animals, but in their adult stage failed to transmit the disease to two susceptible animals.

(2) Ticks belonging to the same batches which were feeding on two animals rendered immune to East Coast fever by inoculation, in the nymphal stage, did not transmit the disease in their adult stage to six animals, thus proving that the brown tick which has become infected in one stage, cleans itself in the following stage by feeding on an immune or susceptible animal.

(3) Ticks which became infected with East Coast fever in their larval stage, and which passed their nymphal stage on a rabbit, did not prove to be infective in their adult stage for susceptible cattle. This conclusion bears out that given above (2), showing that a tick loses its infectivity the first time it feeds on an animal susceptible or immune to East Coast fever.

(4) Clean or infective ticks feeding on an animal which has recovered from an attack of East Coast fever do not transmit the disease in their next stage. This conclusion is in support of experiments undertaken eight years ago (*vide* Annual Report of the Government Veterinary Bacteriologist, 1904–5).

(5) It has been demonstrated that certain batches of ticks collected at the same time and which fed under similar conditions did not transmit the disease in their next stage, even when infected in great numbers and on numerous animals. Other batches of ticks reared in exactly the same way and under similar conditions only infected a few animals, whilst again other ticks proved infective in almost every instance, even when a minimum number were used.

It is difficult to give an explanation of this fact, but it is quite likely that outside conditions have some influence. The ticks which did not transmit the disease were bred during the coldest time of the year. This may perhaps explain the fact that during the winter months the infection in the field is not so active as during the summer months, remembering at the same time that during the winter months tick life is generally weaker than in the summer.

ORDINARY MONTHLY MEETING.

October 18, 1911.

The Vice-President, H. H. W. PEARSON, in the Chair.

Nomination: D. SUTHERNS, B.A., Natal, by C. STEWART and L. PÉRINGUEY.

Exhibition: The Chairman announced that the allotment of the grants in aid of research shall take place on the 27th inst.

The Vice-President exhibited a photograph of the North Wall of the Cave at Heerenlogement, Cape Colony. The photograph shows the name of "F. Vailant," which was presumably inscribed by the traveller in the course of his journey in Namaqualand in 1783. The inscription was seen and described by Sir J. E. Alexander in 1836. The Cave is situated in the sand belt, about 40 miles S.E. from the mouth of the Oliphant's River. The wall also bears the name of K. Zeyher, with the date 1829.

Communications:—

"The Spectrum of Ruby," Part III., by J. Moir.

Two further very faint spectrum-lines are described. The artificial ruby has been analysed, and chromium detected as the colouring matter. When a ruby is heated above 300° C., it changes, through scarlet and brown, to the colour of chromium glass, and all the characteristic spectrum lines disappear. It recovers completely on cooling. The effect of heat on the birefringence of corundum has been studied, and has been found to be insignificant. The spectrum of ruby is therefore due to chromium in a special atomic condition, which does not apparently occur elsewhere in Nature.

"Some Causes and Effects of Variation in the Range of Temperature," by Dr. and Mrs. J. R. Sutton.

This paper contains the results of a discussion of some of the more salient meteorological aspects of a variation in the range of temperature. It deals in a general way with the changes of temperature, moisture, pressure, and sunshine, which go with a variation in the range of temperature, monthly means being used. Harmonic constants of barometric pressure and temperature are computed for months of great and small range of temperature respectively.

"Algebraical Development of the Elliptic Perturbative Function used in the Theories of Planetary Motion," by R. T. A. Innes.

The paper presents tables whereby the functions, which operate on the ratio of the semi-axes, can be easily calculated to any order of the eccentricities and mutual inclination so far as regards primary and secondary terms which alone have any importance in the planetary theories. The paper concludes with an explicit development of the secular part of the perturbative function to any order.

"A supposed new Mineral from Du Toitspan, Kimberley," by B. de St. J. van der Riet. The supposed new mineral from Du Toitspan, Kimberley, reported in *Nature* (September 7th) by Mr. J. R. Sutton, appears to the author to be derived from a well-known artificial material, viz.: commercial calcium carbide. It is certain that acetylene generators have been in use on the mine for years, and it is quite possible that a

portion of the waste from the acetylene machines has in some manner found its way to the pulsator, where the supposed mineral was discovered. It has been found possible to compare specimens of the substance referred to (kindly supplied by the general manager of the De Beers' Co.) with the lumps and pellets which settle in the lime residue from generators supplying acetylene gas to the Chemical Laboratory of Victoria College (Stellenbosch). In chemical as well as physical characters there is an unmistakable similarity between the two products. Thus, (1) slaked lime, which of course accompanies carbide pellets, can be detected in some of the cavities on surfaces of the pulsator pellets. (2) Variations in hardness, form, colour, fracture, size of pellets, and peculiar markings are faithfully reproduced. (3) In either case the lumps and pellets vary in composition from iron carbide, attacked by dilute acids, to iron silico-carbide, which is attacked by hydrofluoric acid, but not by hydrochloric and sulphuric acids. (4) The pellets from either source give off an odour of acetylene when crushed. (5) The pulsator pellets, as well as ordinary carbide pellets, do not contain, as far as can be found, notable quantities of titanium. In an iron mineral derived from the ilmenite of "blue ground," by reduction at a high temperature, one would certainly expect to find titanium.

"Further Magnetic Observations in South Africa during the Years 1910 and 1911," by J. C. Beattie.

The communication contains the reduced results of observations in various parts of South Africa during 1910 and 1911 for determining the secular variation of the magnetic elements. It also contains results of additional observations in the West Transvaal and the East of Cape Province, with a discussion of the magnetic states of these regions.

"Action of Radium Salts on Glass," by W. A. Douglas Rudge.

An account of experiments carried on during the past three years in order to study the prolonged action of radium salts upon glass. Small quantities of radium were sealed up in thick-walled tubes, and the extent to which the colouration extended determined by cutting up sections of the tube, polishing the ends, and examining with a microscope. The tint developed depended upon the nature of the glass employed, and the depth of penetration depended upon the structure of the glass. Many kinds of glass show a "zonal" structure, and an abrupt change in the depth of colouration appears at the junction of successive zones. The width of the zones were measured with a micrometer, the first and darkest being 0·27 mm.; the others extended right up to the external walls of the tube, a distance of 2·48 mm. from the bore. If the colouration is due to X particles alone, the range must be much greater than would be deduced from the experiments of Rutherford and Joly. There is evidently some obstacle met with to the free passage of the rays at each zonal layer, as the colouration shows. The action of even a very impure radium salt is

comparatively rapid; a few milligrammes of a salt containing about one-thousandth of its weight of radium causes a very definite colouration at the end of 20 days, the first zone being then clearly defined. The colouration must be due to B and Y, as well as X-rays and emanation.

"A New Species of Mesembryanthemum from the Transvaal; and Notes on the Genus Ficus," by J. Burtt-Davy.

LIST OF FELLOWS AND MEMBERS.

December 31, 1911.

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J. C. Beattie.
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J. Moir.
L. Péringuey, *General Secretary.*
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Anderson, A. J., *M.A., M.B., D.P.H.*, Town House, Cape Town.
Beattie, J. C., *D.Sc., F.R.S.E.*, South African College, Cape Town.
Behr, H. C., P.O. Box 1167, Johannesburg.
Bohlé, H., *M.I.E.E.*, South African College, Cape Town.
Broom, R., *M.D., D.Sc.*, Springs, Transvaal.
Burtt-Davy, J., *F.L.S., F.R.G.S.*, Agricultural Department, Pretoria.
Caldecott, W. A., *D.Sc.*, P.O. Box 1167, Johannesburg.
Corstorphine, G. S., *B.Sc., Ph.D.*, P.O. Box 1758, Johannesburg.
Crawford, L., *M.A., D.Sc., F.R.S.E.*, South African College, Cape Town.
Gilchrist, J. D. F., *M.A., D.Sc., F.L.S., Ph.D.*, South African College, Cape Town.
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Hahn, P. D., *M.A., Ph.D.*, South African College, Cape Town.
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Halm, J. K. E., *Ph.D.*, Royal Observatory, Cape.
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Ingle, H., Gorleston-on-Sea, near Great Yarmouth, England.

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Kynaston, H., *B.A.*, *F.G.S.*, Geological Survey, Pretoria.
Lehfeldt, R. A., *B.A.*, *D.Sc.*, School of Mines and Technology, Johannesburg.
Lounsbury, C. P., *B.Sc.*, Department of Agriculture, Pretoria.
Marloth, R., *Ph.D.*, *M.A.*, Church Street, Cape Town.
Mellor, E. T., *D.Sc.*, Geological Survey, Pretoria.
Moir, J., *M.A.*, *D.Sc.*, *F.C.S.*, Mines Department, Johannesburg.
Morrison, J. T., *M.A.*, *B.Sc.*, *F.R.S.E.*, Victoria College, Stellenbosch, C. C.
Muir, T., *C.M.G.*, *M.A.*, *LL.D.*, *F.R.S.*, Department of Education, Cape Town.
Nevill, E., *F.R.S.*, The Observatory, Durban, Nat.
Ogg, A., *M.A.*, *B.Sc.*, *Ph.D.*, Rhodes University College, Graham's Town.
Pearson, H. H. W., *M.A.*, *Sc.D.*, *F.L.S.*, South African College, Cape Town.
Péringuey, L., *D.Sc.*, *F.E.S.*, *F.Z.S.*, South African Museum, Cape Town.
Pole-Evans, I. B., *B.Sc.*, Department of Agriculture, Pretoria.
Purcell, W. F., *B.A.*, *Ph.D.*, Diep River, C. P.
Reunert, T., *M.I.C.E.*, P.O. Box 92, Johannesburg.
Roberts, N. W., *D.Sc.*, *F.R.A.S.*, Lovedale, C. P.
Robertson, G. W., *M.R.C.S.*, Government Bacteriological Laboratory, Cape Town.
Rogers, A. W., *Sc.D.*, *F.G.S.*, Geological Survey, Cape Town.
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Sutton, J. R., *Sc.D.*, P.O. Box 142, Kimberley, C. P.
Theiler, A., *C.M.G.*, *D.Sc.*, Agricultural Department, Pretoria.
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de Villiers, *Rt. Hon.* J. H. Lord, *P.C.*, *K.C.M.G.*, *B.A.*, *LL.D.*
Warren, E., *D.Sc.*, The Government Museum, Maritzburg, Nat.
Wilson, A. Marius, *M.D.*, Cape Town.

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Calverley, Major E. L., 70, Chaucer Road, Bedford, England.
Chubb, E. C., *F.Z.S.*, Durban Museum, Natal.
Cornish-Bowden, A. H., Surveyor-General's Office, Cape Town.
Churchill, Hon. Frank F., Houses of Parliament, Cape Town.
Clark, G. M., *M.A.*, *A.M.I.C.E.*, 410, Consolidated Buildings, Johannesburg.
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Currlé, (Miss) L., Klipfontein, Postmasburg, Griqualand W., C. P.
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Dinter, K., Windhoek, German South-West Africa.
Dodds, W. J., *M.D.*, *D.Sc.*, Valkenberg, Mowbray, C. P.
Dodt, J., Museum, Bloemfontein, O. F. S.
Drege, J. L., Port Elizabeth, C. P.
Dreyer, T. F., *B.A.*, *Ph.D.*, School of Agriculture, Grootfontein, C. P.
Dru-Drury, E. G., *M.D.*, *B.Sc.*, *D.P.H.*, High Street, Graham's Town, C. P.
Duthie, Miss A. V., *M.A.*, Victoria College, Stellenbosch, C. P.
Engelenburg, F. W., *Ph.D.*, Offices of the *Volkstem*, Pretoria, Trsv.
Evans, M. S., *F.Z.S.*, Durban, Natal.
Eyles, F., Mazoe, Rhodesia.
Fairbridge, W. G., *B.A.*, 141, Longmarket Street, Cape Town.
Feltham, H. L. L., P.O. Box 46, Johannesburg.
Fenton, J. de, *Ph.D.*, *F.R.A.S.*, P.O. Box 2561, Johannesburg.
Fincham, G. H. H., *M.A.*, Hopewell, Imvani, C. P.
Findlay, F. N. R., Rustenburg, Trsv.
Fletcher, W., Ratel River, Caledon, C. P.
Flint, *Rev.* Wm., *D.D.*, Rosebank, C. P.
Fourcade, H. G., Storm River, C. P.
Franks, *Sir* Kendal, *M.D.*, Johannesburg.
French, G., Public School, Claremont, C. P.
Fry, Harold A., P.O. Box 46, Johannesburg.
Fuller, C., *F.E.S.*, Agricultural Department, Maritzburg, Nat.
Fuller, E. B., *M.B.*, *F.R.C.S.Ed.*, New York Buildings, Cape Town.
Galpin, E. E., *F.L.S.*, Queen's Town, C. P.
Georges, E. H. L., Department of the Interior, Pretoria.
Gray, Chas. J., P.O. Box 401, Pretoria.
Grimmer, J. R., De Beers Consolidated Mines, Ltd., Kimberley.
Guest, Hon. Ivor, Klerksdorp, Transvaal.
Gunning, J. W. B., *Ph.D.*, Museum, Pretoria.
Hardenberg, C. B., *M.A.*, Agricultural Department, Pretoria.
Harger, H. S., P.O. Box 1945, Johannesburg.
Hayward, S. H., *L.D.S.*, Colonial Mutual Buildings, Cape Town.
Henkel, J. S., Forest Department, Knysna, C. P.
Henderson, J. McLelland, *Ph.D.*, Johannesburg.
Hewitt, J., *B.A.*, Albany Museum, Graham's Town, C. P.
Heymans, A., *M.D.*, P.O. Box 259, Pretoria.
Hoffe, J. A., *A.M.I.C.E.*, P.O. Box 1401, Cape Town.
Howard, C. W., *B.A.*, P.O. Box 255, Lourenço Marques, Moz.
Howard, R. N., *M.R.C.S.*, O'okiep, C. P.
Jagger, J. W., *F.S.S.*, *M.L.A.*, St. George's Street, Cape Town.
Janisch, N., Office of the Administrator, Cape Town.
Janse, A. J. T., Normal College, Pretoria.
Jardine, W., P.O. Box 153, Cape Town.
Johnston, W., Rhodes Buildings, Cape Town.
Jorissen, E., *Ph.D.*, P.O. Box 605, Johannesburg.
Kannemeyer, R. D. R., Smithfield, O.F.S.
Kanthack, F. E., *A.M.I.C.E.*, Irrigation Office, Pretoria.
Kehoe, D., *M.R.C.V.S.*, Department of Agriculture, Pretoria.
Kensit, Miss H. M. L., *B.A.*, Sherwood, Kenilworth, C. P.
Kirkman, A. H., *F.R.C.S.E.*, Queenstown, C. P.
Kitching, C. McGowan, *B.A.*, *M.D.*, Church Street, Cape Town.
Kolbe, Rev. F. C., *B.A.*, *D.D.*, St. Mary's Presbytery, Cape Town.
Krapohl, J. H. C., *B.A.*, Concordia, C. P.
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Legat, C. L., Department of Forestry, Pretoria.
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Leslie, T. N., Vereeniging, Trsv.
Leviseur, M., Bloemfontein, O. F. S.
Lewis, Alfred D., *B.A.*, Irrigation Department, Cape Town.
Lightfoot, R. M., *F.E.S.*, Museum, Cape Town.
Lindley, J. B., *C.M.G.*, *M.A.*, *LL.B.*, Claremont, C. P.
Lithman, K. V., P.O. Box 640, Cape Town.
Littlewood, E. T., *M.A.*, Wynberg, C. P.

Logeman, W. H., *M.A.*, South African College, Cape Town.
Lotz, H., *Ph.D.*, Berlin.
Louw, A. J., *B.A.*, *B.Sc.*, Heidelberg, Transvaal.
Lyle, J., *M.A.*, Grey College, Bloemfontein, O.F.S.
MacLean, L., Union Castle Company, Cape Town.
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Malleson, P. R , Ida's Valley, Stellenbosch, C. P.
Mally, C. W., *M.Sc.*, Graham's Town, C. P.
Mann, G., South African Association, Cape Town.
Mansergh, C. W. L., Public Works Department, Cape Town.
Marshall, G. A. K., *F.E.S.*, *F.Z.S.*, 6, Chester Place, London, W.
Maxfield, J. W., *A.R.C.S.*, Oudtshoorn District, C. P.
McLeish, R. D., De Beers Consolidated Mines, Ltd., Kimberley, C. P.
Meiring, I. P. Van H., Worcester, C. C.
Melvill, E. H. V., *F.R.G.S.*, P.O. Box 719, Johannesburg.
Mendelssohn, S., Kensington Court Gardens, London.
Menmuir, R. W., *A.M.I.C.E.*, Church Square, Cape Town.
Milligan, A., Durban, Natal.
Mitchell, D. T., *M.R.C.V.S.*, Department of Agriculture, Pretoria.
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Nobbs, E., *Ph.D.*, Department of Agriculture, Salisbury, Rhodesia.
Orpen, J. M., P.O. Clearwater, viâ Barkly East, C. P.
Park, M. H., *M.A.*, *LL.D.*, Cape Town.
Phillips, E. P., *M.A.*, Museum, Cape Town.
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Potts, G., *B.Sc.*, *Ph.D.*, Bloemfontein, O. F. S.
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Quekett, J. F., *F.Z.S.*, The Museum, Durban, Natal.
van der Riet, B., *Ph.D.*, *M.A.*, Victoria College, Stellenbosch, C. P.
Ritchie, W., *M.A.*, South African College, Cape Town.
Rix-Trott, H., Lower Hutt, near Wellington, New Zealand.
Rose, J. G., *F.C.S.*, Agricultural Department, Cape Town.
Russell, W. A., *M.A.*, Education Department, Cape Town.
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Saxton, W. T., *M.A.*, *F.L.S.*, South African College, Cape Town.
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Sclater, W. L., *M.A.*, *F.Z.S.*, 10, Sloane Court, London.
Sheppard, P. A., Beira, Moz.
Silberbauer, C. F., Cape Town.
Simpson Wells, A., *M.A.*, *M.D.*, *F.R.C.S.E.*, Cape Town.
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Smuts, *Hon.* J. C., *B.A.*, *LL.B.*, Department of the Interior, Pretoria.
Snape, A. E., *A.M.I.C.E.*, South African College, Cape Town.
Stewart, C. B., *B.Sc.*, Meteorological Department, Cape Town.
Stewart, T., *F.G.S.*, *M.I.C.E.*, St. George's Street, Pretoria.
Stoney, W. W., *M.D.*, Kimberley, C. P.
Stott, C. H., *F.G.S.*, Pietermaritzburg, Natal.
Swierstra, C. J., Transvaal Museum, Pretoria.
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Thompson, W. Wardlaw, *F.Z.S.*, Cape Town.
Tooke, W. Hammond, Graham's Town, C. P.
Toit, P. J. du, Agricultural Department, Pretoria.
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Tucker, *Hon.* W. K., *C.M.G.* (Senator), Johannesburg.
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Wager, H. A., *A.R.C.S.*, Transvaal University College, Pretoria.
Walker, A. R. E., *B.Sc.*, *A.R.C.S.*, South African College, Cape Town.
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Walsh, A., P.O. Box 39, Cape Town.
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Wessels, M. L., *F.R.G.S.*, Green Point, Cape Town.
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White, Franklin, Bulawayo, S. Rhod.
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Wood, H. E., *M.Sc.*, *F.R.A.S.*, Transvaal Observatory, Johannesburg.
Wood, J. Medley, Durban, Natal.
Young, A., *M.A.*, *B.Sc.*, South African College, Cape Town.
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OF THE

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VOL. II.

A PRELIMINARY DETERMINATION OF THE ABSORPTION OF LIGHT BY THE EARTH'S ATMOSPHERE.

By A. W. Roberts, D.Sc., F.R.A.S., F.R.S.E., F.R.S.S.Af.

(Read October 20, 1909.)

In almost all stellar photometric work, a knowledge of the amount of light absorbed by the Earth's atmosphere is necessary. In certain very refined variable star work, as accurate a determination as possible of this absorbing quality of the atmosphere is desirable.

It is known to all that if there were no atmosphere surrounding the Earth the stars would appear brighter. The air acts as an obscuring veil dimming their lustre.

The thicker the quantity of air through which the observer views the stars the greater will be their diminution in brightness.

The minimum diminution takes place when the star being observed is in the zenith; the maximum when it is on the horizon.

The amount of light lost by a star when in the zenith is called the *coefficient of atmospheric absorption.* It is the difference in brightness between what the star would be if there were no air, and what it is when viewed through about two hundred miles of air.

Once this coefficient is known, it is possible to determine the loss of light at any altitude, always assuming that the atmosphere is homogeneous in structure.

Many determinations of this coefficient have been made by astronomers at various parts and heights on the earth's surface.

These determinations naturally vary with the conditions under which they were made. It is matter of common experience that out on the Karoo the stars shine far more brilliantly than they do in the neighbourhood of Cape Town.

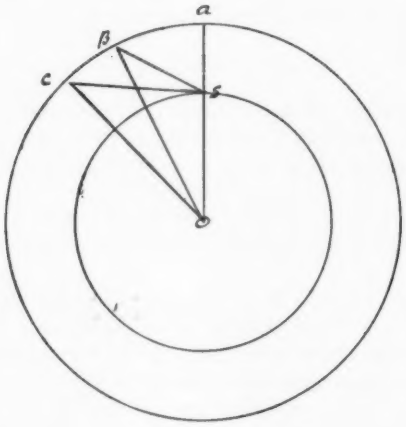
In this uncertainty it seemed to me desirable to make a determination of the coefficient of absorption for this part of Cape Colony—the Eastern province. This paper is a brief and preliminary statement of a single determination made on the summit of one of the hills of the Winterberg Range.

I shall divide my paper into three sections :—

(1) A statement of the Problem.
(2) Consideration of the Winterberg Observations.
(3) Deductions therefrom.

1. Statement of the Problem.

I shall only deal with simple relations, and thus present the problem in its simplest form.



Let—

s represent an observing station on the earth's surface,
sa, *sβ*, *sc* different altitudes of a star when viewed from the station *s*,
sa the height of the atmosphere,
os the radius of the earth,

and let—

L = amount of light of a star seen in the zenith direction sa, *if there were no atmosphere*,
$= m_0$ in magnitudes,
Lq = amount of light of the same star seen in the direction sa,
$= m$, the apparent magnitude of the star,
Lq' = amount of light of the same star seen in the direction $s\beta$,
$= m_1$.

Therefore, if K is the light ratio—

$$\frac{L}{Lq} = K^{m-m_0} \qquad \frac{Lq}{Lq'} = K^{m_1-m}$$

$$\frac{L}{Lq} = K^{m_1-m_0}$$

$$\frac{1}{q'} = K^{m_1-m_0}$$

or—

$$t \log \left(\frac{1}{q}\right) = (m_1 - m_0) \log K$$

$$m_1 - m_0 = t\left(\frac{\log \frac{1}{q}}{\log K}\right)$$

putting—

$$\frac{\log \frac{1}{q}}{\log K} = \gamma$$

$$m_1 - m_0 = t\gamma$$

now—

$$t = \frac{\beta s}{as}$$

let—

$$as\beta = \theta,$$
$$os = 1,$$
$$sa = d,$$

then it can be easily shown from a simple consideration of the figure that—

$$t^2 d + 2t \cos\theta - d - 2 = 0,$$

or—

$$t = \frac{-\cos\theta + \sqrt{(d+1)^2 - \sin^2\theta}}{d},$$

and—

$$m_1 - m_0 = \frac{\gamma}{d}\left\{\sqrt{(d+1)^2 - \sin^2\theta} - \cos\theta\right\}.$$

the right-hand number of this equation is the correction for atmospheric absorption, and includes as unknown quantities the height of the atmosphere = d, and the coefficient of absorption = γ.

This final equation can be put in the form—

$$(m_z - m_o)^2 + 2(m_z - m_o)\cos\theta\frac{\gamma}{d} - \gamma^2\left(1+\frac{2}{d}\right) = 0.$$

Returning to the value of t, viz.—

$$t^2 d + 2t\cos\theta - d - 2 = 0,$$

we may remark that when d is very small, that is when the ratio of the height of the air to the radius of the earth is practically zero, the above expression becomes—

$$2t\cos\theta = 2,$$
$$t = \sec\theta,$$

and—

$$(m_z - m_o) = \gamma\sec\theta.$$

This limiting value holds good for zenith distances up to 70°, but after that it ceases to hold good.

The rigorous equation of condition—

$$(m_z - m_o)^2 + 2(m_z - m_o)\cos\theta\frac{\gamma}{d} - \gamma^2\left(1+\frac{2}{d}\right) = 0,$$

well represents the relation between atmospheric absorption and zenith distance at any altitude, always premising that the atmosphere consists of homogeneous concentric spherical shells round the earth's surface, and that it is free of foreign bodies such as dust or masses of vapour.

The variations in the barometer for different regions of the earth's surface show that neither of these considerations is admissible.

2. Consideration of Winterberg Observations.

Over five hundred observations were made from the summit of a hill, whose altitude would be about 4,000 feet.

A number of stars were selected, and their decrease in brightness noted as they passed from the zenith to the horizon.

These quantities were plotted down and the interpolating curve drawn. The following are measures on the curve :—

Altitude 79°	Decrease = 0·64 m.
81	0·75
83	0·95
85	1·28
87	1·82
89	2·70

It was at first hoped that these observations would yield both the coefficient of absorption ($= \gamma$) and the height of the atmosphere ($= d$), but a variety of solutions confirmed me in the view that a far more refined series of observations would require to be made before any value of the height of the atmosphere worthy of credence would emerge from the equations.

In the present solution, therefore, the coefficient of absorption is expressed as a function of the height of the atmosphere.

We may, however, indicate an approximate solution in which the height of the atmosphere is also determined.

A first solution yields as a value of the coefficient of atmospheric absorption—

0·20 m.

As the magnitudes given above are those which are obtained from a comparison with zenith magnitudes, it is necessary to add to these differences the coefficient of absorption in order to obtain the absolute decrease in brightness due to the amount of atmosphere passed through. We may term these new quantities absolute values: they represent the difference between the observed brightness of a star at certain zenith distance and the real brightness of the star if there were no atmosphere.

The foregoing table of decrease in magnitude becomes therefore by the addition of the coefficient of absorption—

Zenith distance	Decrease in brightness
79°	0·84 m.
81	0·95
83	1·15
85	1·48
87	2·02
89	2·90

And the resulting equations of condition are—

$$(0{\cdot}84)^2 + 0{\cdot}321\,\frac{\gamma}{d} - \gamma^2\left(1 + \frac{2}{d}\right) = 0$$

$$(0{\cdot}95)^2 + 0{\cdot}296$$
$$(1{\cdot}15)^2 + 0{\cdot}281$$
$$(1{\cdot}48)^2 + 0{\cdot}257$$
$$(2{\cdot}02)^2 + 0{\cdot}210$$
$$(2{\cdot}90)^2 + 0{\cdot}099$$

From which we obtain as final equations—

$$6\gamma^2\left(1+\frac{2}{d}\right)-1{\cdot}464\,\frac{\gamma}{d}-17{\cdot}611=0$$

$$+0{\cdot}390\,\frac{\gamma}{d}+\ 3{\cdot}117=0$$

a solution of which yields—

$$\gamma = 0{\cdot}17 \text{ m.}$$
$$d = 0{\cdot}005.$$

Reducing the coefficient of atmospheric absorption to sea-level, we have the final value for this important factor—

0·19 m.

The value of the height of the atmosphere obtained from the equations, viz., 0·005, or 20 miles, is of course too small. But this small value may mean that above 20 miles the air is too rare to stop light to any appreciable extent.

3. Deductions from the Above.

The principal determinations of the coefficient of absorption are—

Seidel	0·25 m.
Langley	0·13
Pritchard	0·19
Muller	0·21
Pickering	0·25

The mean of these results is—

0·21 m.,

agreeing very closely with that obtained at Lovedale—

0·19 m.

Taking the mean of all the results, we obtain as the value of the coefficient of atmospheric absorption—

0·20 m.,

which, interpreted into other terms, means that 17 per cent. of all rays that strike the atmosphere perpendicularly are absorbed by the atmosphere. That is, a star in the zenith shines with 83 per cent. of its intrinsic brightness; on the horizon this is reduced to such an extent that the star shines with only about one-fortieth of its zenith brightness.

The foregoing investigation was undertaken for the purpose of obtaining a value of the coefficient of absorption true for South Africa. The results obtained by different astronomers at different parts of the earth's surface indicates that it is not the same for all regions. The presence of moisture, of dust particles, will modify to an appreciable extent the absorbing quality of the atmosphere.

The present investigation is also, as the title indicates, simply preliminary. For a determination of the height of the atmosphere by this method the most refined photometric equipment is necessary. And I am confident that an investigation so carried out will yield results comparable in exactness and finality with any of the indirect ways of obtaining the height of the atmosphere.

NUTMEG POISONING.

By A. Marius Wilson, M.D., F.R.S.S.Af.

(Read October 20, 1909.)

A lady, aged 35 years, who had given birth to eight children, had heard that as an abortifacient grated nutmeg was safe and reliable. She therefore carefully grated one nutmeg, boiled it with a breakfast-cupful of beer (brewed in the Peninsula) and drank every drop of the mixture about 11 p m., just before getting into bed. Nutmeg she was used to with her food, but very rarely ever touched stimulants. About 5 a.m. next morning she woke "feeling very ill, numb, dull, and heavy all over." She then tried to sit up, but only fell back again, and so roused her husband. To him she complained of "feeling so ill, my heart is jumping, and I think I am going to die." Off he ran for the nearest doctor, who came and saw the patient soon after quarter past five. He found her very excitable about her approaching end, ordered some bromides and also castor oil. The bowels were moved about 11 o'clock.

Later on, as this lady had been a patient of mine for some years, I was called in and saw her at quarter to ten. I found her lying in bed, unwilling to move, eyelids closed, and heard from her much of what I have already related. It seemed to be an effort on her part to speak; I therefore obtained more details from her husband. When the attack had quite passed away, she informed me that, though she might have appeared very drowsy, she was wide awake and was listening keenly to everything said, but felt she could not open her eyes or join in the conversation. There was no vomiting, nor even any nausea, but there was great thirst; the lips, tongue, palate, and throat were very dry and parched, and this continued for three days. The pupils were equal and neither contracted nor dilated. The eyelids were closed and, in common with the rest of the muscular system, seemed to have lost much of their power. The heart and pulse were beating regularly and at a fairly normal rate. The urine showed nothing. The most marked feature was the feeling of impending death and constriction of the thorax. Though talking seemed to be an exertion, the patient many times made the

statement, "I feel very ill." She remained in bed for four days on antispasmodic treatment, getting up on the fifth day feeling very weak. Since then she has quite recovered, but feels certain she will never forget the awful sensation of approaching dissolution. The abortive treatment was unsuccessful.

I can only find a record of four cases of nutmeg poisoning, and in two the spice was taken with the object of producing abortion—in each case uselessly.

The first: The patient was three months advanced in pregnancy, and she took three grated nutmegs, and would have taken more only she began to be nauseated. Three hours later she started vomiting, and soon relapsed into a state of low muttering delirium. In this case also the feeling of impending death was pronounced. This case recovered on the second day.*

The second: The patient, aged 26 years, was one week over her menstrual period, and she took two bruised nutmegs in a little gin. She vomited, was very drowsy, had normal pupils, was giddy and felt faint on attempting to stand, and complained of a sensation of great tightness across the chest. She recovered after two days.†

The third: A boy, aged 3 years, consumed part of five nutmegs. He slept for 30 hours. Symptoms: Vertigo, narcosis, dilated pupils, no delirium.‡

The fourth: A farmer, who was troubled with boils, took one grated nutmeg in milk at night. He found, when he woke at 6 o'clock next morning, that he was giddy, could not distinguish objects around, and his head was paining him. When seen by the doctor he appeared drowsy, but could be roused when spoken to sharply. He then complained of great pain in his head, great thirst, that his mouth and tongue were parched, and much numbness of the limbs. Pulse 70, regular; heart sounds normal; pupils slightly contracted. Except for a slight headache, next morning he was quite well.§

The greater part of the world's supply of nutmegs comes from the Banda Islands, a group in the Malayan Archipelago. These islands are subject to alteration in number owing to frequent volcanic eruptions. They were discovered by the Portuguese in 1511 and held by them till the next century, when the Dutch took possession. From that time onwards the ownership drifted between Holland and England, but the islands have been Dutch colonies since the Treaty of Paris in 1814.

The nutmeg of commerce is the dried seed of *Myristica fragrans* divested of its coverings, of which the fibrous substance of crimson colour, when dried, becomes the mace of commerce. The seed is

* Reading, *Therap. Gazette*, 1892.
† Simpson, *Lancet*, 1895.
‡ Sawyer, *N.Y. Med. Journ.*, 1889.
§ Bentlif, *British Med. Journ.*, 1889.

composed chiefly of starch, a compressed oil (nutmeg-butter) and a volatile oil. The ripe fruit is carefully gathered, split in half, and therefrom is taken the single seed. The seed is then carefully dried in a special drying-house—the process taking many weeks. When dry, the hard covering is cracked and the kernel is then treated with dry lime to prevent germination. This latter process is said to be unnecessary if the drying has been properly carried out. The whole fruit in syrup is used as comfit in the Dutch East Indies.

In medicine, the nutmeg is used chiefly to cover the taste of less pleasant-tasting drugs, and locally it is thought to be of use in rheumatic troubles. The dose of the powder is given as from 5 to 15 grains. In the case I have described, not more then 84 grains can have been taken. I asked my patient to pick out a nutmeg from a tinful as nearly as possible exactly like the one she grated and took. The one selected weighed 84 grains. Now, under ordinary circumstances, that much nutmeg should not produce such violent symptoms. It is not unreasonable to suppose that there must have been very many cases of little children putting away a great deal more than 84 grains, and not suffering any very ill-effects. The spice is to be found in (I suppose) every household throughout the civilised world. It is not usual to keep it under lock and key, and little children are very inquisitive and taste even repugnant things. The spice is used also very largely in cooking, and if as small a dose as 84 grains is dangerous, there should be numerous cases of ill-effects arising in persons sensitive to this drug who are taking fair-sized amounts in their food every day. Surely one should look for poisonous symptoms when the fruit is used as a sweetmeat.

I believe the explanation of poisonous symptoms is the condition of the nutmeg: germination must have commenced. It is not unreasonable to suspect that a few nutmegs have escaped from the thorough destruction of the power of germinating—the germination may have started and then been killed, but after some chemical change has taken place. Here, in Cape Town, we have a seed very largely eaten by children—the pine seed, known locally as the *Dana pitje*. No untoward symptoms arise even when dozens of these "pitjes" are eaten; but let the child eat one that has started germinating and the consequences are extremely serious.

As I have already stated, recorded cases of nutmeg poisoning are not numerous, nor have I heard of any instance where the result was fatal. The symptoms described in the cases I have referred to have varied, and I think there is room for closer observation. I should like to repeat that in my case the most pronounced symptom was the expectation of approaching dissolution.*

* See also *Lancet*, i., 387, 1908, and *British Medical Journal*, i, 495, 1908, for report of an address on "Nutmeg Poisoning," by Prof. A. R. Cushny, M.D., F.R.S.

THE ODYSSEY OF OUR BUSHMAN BOY.

By Miss L. Currlé.

(Communicated by L. Péringuey, F.R.S.S.Af.)

(Read October 20, 1909.)

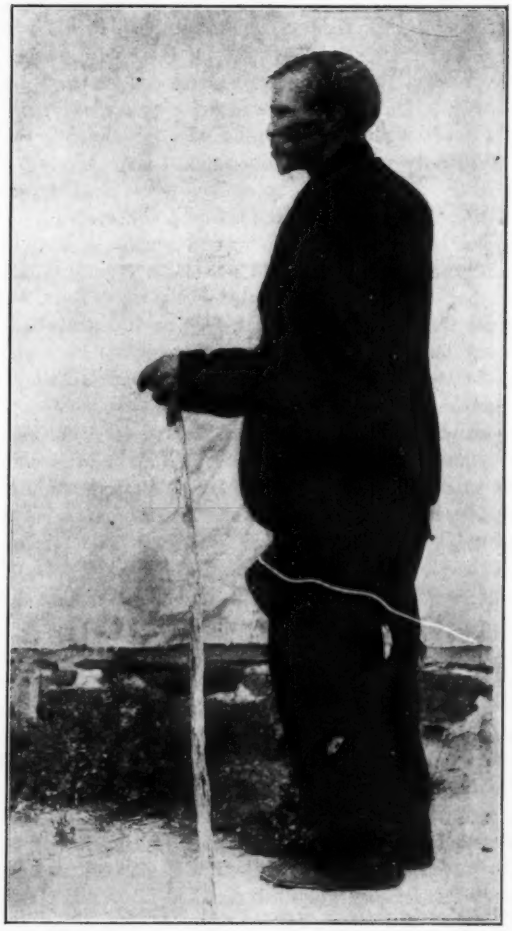
Our old boy's earliest recollections are centred in the town of Graaff-Reinett, C. C. He does not remember his parents or relations—he thinks they were murdered by Kafirs; he was brought up by an "Ou Bass" Hendrick Pretorius, who had a long, white beard, and was of a kindly disposition. This "Ou Bass" had two large erven, and taught the little Bushman—in company with his sons—the cultivation of same, and thus Gert became a good gardener. He remembers that the home and erven were situated towards sunset near the market, and that the "Ou Bass" had slaughter- and baking-houses; he was taught in both trades, and is still, in spite of his great age, the cleanest butcher we ever had on the farm. In his own words "Cornelius Somerset zey was de Commandant van de Kaap" (probably Lord Somerset, who was Governor from 1813–26). The Kafirs were troublesome and warlike. He distinctly remembers soldiers and burghers being called out to meet the advancing King-kop Kafir; he wanted to go out with his young masters, but the "Ou Bass" said he was too young. He says he heard the booming of cannons, and vividly remembers a detachment of the King's Dragoons falling into the enemies' hands, the Kafirs afterwards riding the fine horses. He was taken to the "baai"—no doubt Port Elizabeth—and saw ships with big, fluttering white sails, coming from the sea, and soldiers disembarking. His "Ou Bass," sons, and family joined the big trek to Natal (1833); he says it was a very large trek, consisting of a great number of people, wagons, and oxen; out in the veldt he was taught to handle a gun and shoot game, also to help mind the oxen, out and inspan them, and drive a span or lead it. They used to guard the oxen with loaded guns, in fear of Kafirs and wild beasts; in the evening the wagons were drawn together, guards put out, and when they feared tigers* fires were kept burning all night to

* In South Africa the leopard goes by the name of "tiger."—L.P.

frighten these marauders away. The trek was difficult, he says; the Kafir were first friendly and then hostile, they were very cruel and barbarous and murdered many of the trekkers; after moving about here and there,

those of his masters Pretorius who were still living, trekked back. He remembers being in Bloemfontein, but is not certain whether it was at this period or at a later stage that he went with an English hunting

expedition into the Kalahari desert and up to the Zambesi River. These English were "groot, rijk mensche,"—his expression for people of position and wealth; they had finely equipped wagons and barrels of water. Then



they used to chop up and boil the samma melons in the Kalahari, and made coffee from the juice which ran out of the flesh of the melons through the action of the fire. He knows all the edible wild plants and roots, and tells

us the Stapelia was greatly valued by the Bushmen when thirsty, as it would kill great thirst. The expedition shot a lot of big game; he has seen crocodiles,* lakavanes, haarte-beest, blaau-wilde beest, elands, giraffes, zebras, tigers, lions, leopards, wolves, jackals, wild-dogs, and all kinds of wild buck and small game; he certainly can describe all the spoors† most minutely, and could track them exceptionally well in his younger days; this quality seems to be inherent in the Bushman people, no doubt through long generations of them being engaged in tracking the spoors of game and wild animals. They are also very good herds for all kinds of stock; our old boy will often scold animals roundly, as if he fully expected that they would fully understand his tirades, but always handles them gently, excepting when he is very angry, when a gleam of the latent fierceness of the Bushman will kindle like a flame.

He knows a large variety of fish; and seems to know a great deal about snakes, lizards, scorpions, and poisonous creatures generally.

He remembers the terrible drought when the waters of the Orange River ceased to flow, the waters in the deep pools soon became stagnant, as hundreds of Boer families had taken refuge on the banks, and stood in wagons and tents, their thousands of small stock, cattle, and horses helping to pollute the pools.

Then he wandered to Riet River and worked for "Ou Bass" Zwartz, whose wife eventually died from cancer; old Gert believed to this day that as soon as she died all the bees left, and they could not get any swarms to settle there again. (No doubt a Bushman superstition firmly engraved upon his memory.)

Finally he had to drive some oxen to Jacobsdaal; he was mounted on a fine black horse, when, crossing a drift, he saw a Griqua woman washing clothes. Some of the foremost oxen sniffed the clothes and walked in their direction, where they were drying on some bushes. The woman stood watching, with her hands resting on her enormous hips; it was a critical moment—and old Gert recognised this when he saw how fat and light yellow in colour she was. He sjambokked his horse out of the water and turned the oxen off in the nick of time. Then he greeted the woman. Well, after some conversation, he inquired where she lived, and upon hearing that she was a widow and worked at Mr. John Fraser's, the store-keeper, he decided to seek employment there, as he felt tired of working for "Ou Baas" Zwartz. He took the Griqua woman for a wife; he thought her remarkably fine-looking when she waddled like a duck. Her daughter was Mrs. Fraser's nursemaid. They were in service in this family for many years, and when Mr. Fraser started farming near Hope Town they

* A corruption of the word l'Iguane, which applies here to the Nile Monitor and another species.—L.P.

† Footprints.—L.P.

went with him, also to Van Hoek, near Modder River, having a considerable number of small stock of their own. When the daughter came of age, as it is customary with the Griqua race, a Gaastmaal (a feast) was given to which all the surrounding Griquas had been invited. After a few days' duration the feast was over—not a single sheep or goat were left! They had given their best and their all to their guests. After unaccountable disappearance of some of Mr. Fraser's sheep, Gert and Lena sought other employment; they went to Bloemfontein; their daughter and her young husband quietly left them on the market-place, and have never been heard of again. Her daughter was a good girl, and no doubt felt disgusted about her old master's sheep being made away with.

After a vain search they returned to Modder River, hoping the girl had returned; old Gert was caught doing with some sheep that which he should not have done, and consequently was confined in the Kimberley gaol. Then they entered into the service of Mr. and Mrs. Currlé in 1887.

The old couple were possessed of some goats, some good karrosses, a gun, and two dogs. I was a child then, but can distinctly remember "Oude" Gert, the old and small, keen-eyed and active Bushman, light yellow in colour, having oval-shaped eyes with a quick and shifty glance which seldom looked one straight in the eyes, a flat nose, and prominent cheek-bones. His hair all seemed hundreds of wee, stiff curls, black, but not glossy-looking, it looked dull and greasy; he had a scanty little beard, which now, in .1907, is tinged with white. He could look exceedingly pleasant and harmless, but we found out that he was not altogether trustworthy and reliable, and could easily be influenced for either good or evil.

In 1891 we sold the greater part of our flock and bought a farm—Klipfontein, near Blink-kop (now Postmasburg) district Hay, Griqualand West—to which we soon moved. Old Gert was deeply ashamed to be seen with the remnant of our flock, and tried to hide away from the gaze of strangers by keeping them away from the roads—surely a sign of interest in our affairs! However, the old Bushman nature had to come forth from time to time, and in spite of receiving an ample allowance of food, he had to do something wrong and to take advantage of circumstances, and kill and eat a fat lamb, or even hamel, or take out honey, &c. From time to time the old people would sell a lot of their stock to a travelling hawker and buy all kinds of things, presenting their fellow-servants with gifts, and smoking so much tobacco and drinking such a quantity of coffee that they generally became ill.

Gradually the old girl sickened and became weak-minded; she even stopped telling the harrowing tragedies relating to the Kafir wars. Her one mania was to light a fire.

The old girl died. The other Griqua boy we had dug the grave, with a crypt in the wall towards the sunset, in which the remains were laid.

I read the burial service. When the grave was filled we withdrew. Old Gert felt crushed and restless; eventually he took a hatchet and chopped a lot of thorny shrubs and covered the grave with them. He believes the grave to be haunted and never goes to it.

He married a Bechuana girl later and lived with her for some months, then returned to us half-starved; she had spent all his stock—such a nice little flock—and he returned a sadder, if not a wiser man.

Old Gert is servile in disposition, fluctuates between grateful and revengeful moods in his old age; and thus a chequered career is slowly drawing to a conclusion.

OBSERVATIONS ON SOME SPECIMENS OF SOUTH AFRICAN FOSSIL REPTILES PRESERVED IN THE BRITISH MUSEUM.

By R. Broom, M.D., D.Sc., F.R.S.S.Af.

(Read October 20, 1909.)

The British Museum can still claim to have a larger collection of South African fossil reptiles than any other museum, and this collection is specially valuable in that it contains all Owen's types and most of Seeley's. As it is over thirty years since the large majority of Owen's specimens were described, and as much new light has been thrown on the Karroo reptiles in recent years, it seemed necessary to re-examine a number of the less well-known types.

When recently in London I was enabled, through the kindness of Dr. Smith Woodward and Dr. Andrews, to examine all the specimens I wished to see, and to settle a number of points on which there was some doubt.

Galesaurus.

In 1859 Owen described, under the name *Galesaurus planiceps*, a fairly good skull of a small Cynodont reptile from the Sneeuwberg. In the "Catalogue of the South African Fossil Reptiles," published in 1876, a small, very imperfect skull of a somewhat similar Cynodont is described under the name *Nythosaurus larvatus*. In 1887 a very fine new skull was described by Owen as another specimen of *Galesaurus planiceps*. Seeley, in 1894, pointed out that this last specimen differed in many points from the original type, and proposed for it the new name *Thrinaxodon liorhinus*. Recently two other specimens have been procured, which have not been described but which manifestly belong to the same species as the 1887 specimen.

When the various specimens are carefully studied it becomes clear that Seeley was right in deciding that the specimen described by Owen in 1887 is a very different animal from *Galesaurus planiceps* as represented by the 1859 type. The recently procured specimens, while belonging to the same species as the 1887 specimen, show that the imperfect skull described as *Nythosaurus larvatus* also belongs to the same species. We

must thus regard all the specimens grouped under the name *Galesaurus* as belonging to two genera. The original form is a flat-headed animal, with apparently a dental formula of $i\frac{5}{3}$, $c\frac{1}{1}$, $m\frac{12}{12}$. All the other specimens, which must take the name *Nythosaurus larvatus*, have a deeper, narrower skull, and a dental formula of $i\frac{4}{3}$, $c\frac{1}{1}$, $m\frac{7}{7}$. The difference seen in the teeth of the different specimens of *Nythosaurus larvatus* is due to those in some specimens being of the first set and in others the replacing set.

In *Galesaurus planiceps* 10 molars occupy 20 mm.; in *Nythosaurus larvatus* 7 molars occupy 20 mm.

Scaloposaurus.

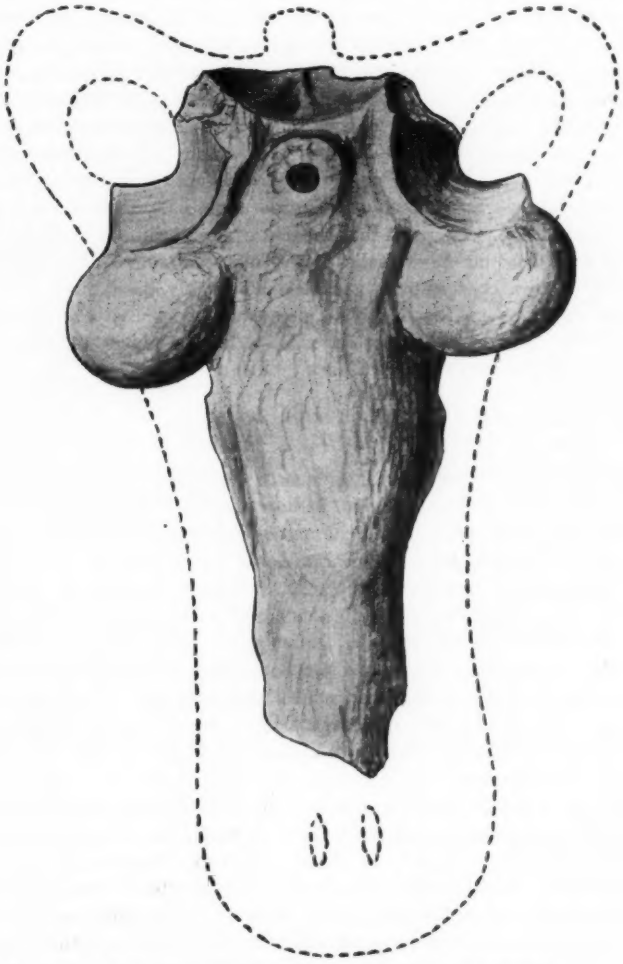
Among the many forms described by Owen in 1876 few are more interesting than the small skull described as *Scaloposaurus constrictus*. No other specimens have ever been discovered of the form, and the original type has apparently never been re-examined since Owen's time. The skull proves to belong to the Therocephalia, but it differs in many ways from any other known Therocephalian. The canines are only slightly enlarged, and there appear to be three—two small ones followed by the main canine. The jugal arch is very slender, and the postorbital arch does not seem to be complete—in this resembling the condition in *Bauria*. Dr. Smith Woodward has kindly had the palate partly cleared at my suggestion, and so far as displayed it is typically Therocephalian, but there appear to be no teeth on the pterygoids. The lower jaw is mainly formed by the dentary, which is remarkable for the small development of the coronoid process. The angular and surangular, though smaller than usual, are quite Therocephalian in structure. *Scaloposaurus* is particularly interesting in being the smallest known Therocephalian. In the small coronoid process and the feebly developed canines it approaches *Galechirus*, but in the imperfect development of the postorbital arch it differs from all other known Therapsidans except the Cynodont *Bauria*. The dental formula is probably $i\,6$, $c\,3$, $m\,9$.

Gorgonops.

In 1876 Owen described a very remarkable skull under the name *Gorgonops torvus*. Though somewhat like other "Theriodont" skulls Owen recognised in it some distinctive characters, and placed it in a special group, the Tectinarialia. Lydekker, who regarded the skull as completely roofed, believed *Gorgonops* was somewhat intermediate between *Pareiasaurus* and the "Theriodonts." On re-examining the skull it appears that though the parietal region is broad there is a distinct temporal fossa, and the condition is very similar to that seen in *Titanosuchus*, which appears to be its nearest ally.

TITANOSUCHUS.

Titanosuchus ferox was described by Owen in 1879 from a very fragmentary specimen. Fragments of jaws are known, and a few limb bones



SKULL OF *Titanosuchus ferox*, Owen. (Greatly reduced.)

and vertebræ, but practically nothing of the skull structure has hitherto been revealed. In the Seeley collection there is the top of a large skull

with a fragment of the maxilla, and it seems fairly certain that the skull is that of *Titanosuchus ferox* or a closely allied form. Though very imperfect, the fragment is sufficient to give a fair idea of the skull. The parietal region is very broad and the temporal fossæ small. The pineal foramen large, and surrounded by a marked thickening of the bone. The occiput slopes downwards and backwards. The orbits are very far apart, and over each is a huge rounded boss of bone, which completely overhangs it. The snout is relatively very long, and on the upper nasal region is a large median thickening as if covered by a horny plate. An attempted restoration is made in the figure. The temporal arches are evidently weaker than in *Tapinocephalus*, and the quadrates are not carried much forward, being probably situated more as in Therocephalians. Few of the sutures are distinct, but it is manifest that the large supraorbital bosses are postfrontal, and that the inner walls of the temporal fossæ are postorbital. The low median boss is mainly frontal but partly nasal.

The fragment of the skull as preserved measures 440 mm., and probably the length of the perfect skull would be about 600 mm. The width across the supraorbital bosses is 310 mm.

Theriognathus.

In the British Museum "Catalogue of the South African Fossil Reptiles," published by Owen in 1876, he describes and figures a fairly large but very imperfect skull under the name *Theriognathus microps*. Owen evidently believed it to be an Anomodont, and speaks of it as "seemingly edentulous," but as evidently distinct from *Oudenodon*. Lydekker came to the conclusion that the skull really belonged to *Endothiodon uniseries*, and in his Catalogue of 1890 says: "The teeth are not shown, but from a comparison with the next specimen [*Endothiodon uniseries*] the generic position of the specimen is quite evident. This is especially shown by the great width of the interorbital region and the natural cast of the right orbit, which evidently had a bony roof identical with that of the next specimen."

The specimen is in such a very bad state of preservation that it is impossible to determine its affinities with certainty, but there is, in my opinion, little doubt that it is not in any way nearly related to either *Oudenodon* or *Endothiodon*. No doubt the interorbital region was broad, as pointed out by Lydekker, but so it is in all Therocephalians. The lower jaw of *Endothiodon uniseries* is known; in fact, the mandible of the type individual is in the South African Museum, and it in no way resembles the jaw of *Theriognathus*. This latter jaw so far as preserved is typically Therocephalian. There is a large coronoid process, a development unknown in any Anomodont, while the angular and articular bones

are also quite Therocephalian. So indeed are all the parts of the skull preserved. Owen is in error in fancying that the depressions seen at the front of the specimen are anterior nares. All the snout-like portion preserved is merely the cast of the upper olfactory region, and probably about 3 inches are lost in front.

The skull does not agree with any known Therocephalian, but I do not think there is any doubt that it must be placed in this group. A number of large Therocephalians are known from the same horizon, and this skull is probably that of an immature specimen of one of the large undescribed forms.

Ælurosaurus.

This genus is founded on a very fine little skull which lacks the postorbital portion. In all respects it is a typical Therocephalian, and the missing portion is doubtless similar to that in typical members of the order. The published figures, and especially Seeley's restoration, give a most misleading idea of the skull. Owing to a thin film of lime having been mistaken for bone, the articulation for the jaw has been considered to be below the posterior margin of the orbit. In reality the jugal passes straight back as in other Therocephalians. Lying inside of the supposed deflected jugal can be distinctly seen the surangular and angular bones. On the left side the mandible is nearly complete, and shows the typical Therocephalian structure. The dental formula seems to me to be $i\,5$, $c\,1$, $m\,5$.

Lycosaurus.

Under this generic name are grouped a number of specimens in the British Museum, some of which pretty certainly belong to different genera.

The type species *Lycosaurus pardalis* is founded on a very badly preserved skull. The right side is much weathered, and only the anterior part of the lower jaw is preserved. On the left side the bones are better preserved, but the whole skull is greatly crushed, and the published figure gives a very erroneous idea of the structure. The skull is typically Therocephalian, and the dental formula appears to be $i\,5$, $c\,2$, $m\,4$, the 1st canine being small and the 2nd large. The molar teeth do not appear to be serrated posteriorly.

The specimen which has been called *Lycosaurus curvimola* is a much better preserved skull, but I think clearly belonging to a different genus from the former. The parietal region is broader than in most Therocephalians. There appears to be no secondary palate and no teeth on the pterygoids. The molar teeth are simple and strongly serrated posteriorly. The dental formula is $i\,4$, $c\,1$, $m\,5$. The curving of the molar series is probably in part due to distortion.

The specimen which forms the type of *Lycosaurus tigrinus* is badly preserved. It appears to have a dental formula of *i* 5, *c* 1, *m* 4 or 5.

The other specimens referred to this genus are all very imperfect.

Cistecephalus.

A number of specimens which have been referred to this genus are in a bad state of preservation. Owen described six species, but these have been reduced by Lydekker to four, and I think it is necessary to still further reduce the number. The type of *C. leptorhinus* seems to me to be merely the snout of a species of *Dicynodon*. Specimen R 1689, which is referred by Lydekker to *C. microrhinus*, is also, in my opinion, the snout of a small *Dicynodon*. The specimens which form the types of *C. planiceps* and *C. bathygnathus* are both in a somewhat unsatisfactory condition, and I do not feel quite satisfied that either is distinct from the type species *C. microrhinus*. The imperfect skull which forms the type of *C. arctatus* should probably be referred to a different genus. The specimen, 47088, pretty certainly does not belong to *Cistocephalus* at all, and more likely to one of the small Endothiodonts, such as *Opisthoctendon*.

Cistecephalus is a very interesting small Anomodont, and is evidently the last stage in the development of the Dicynodonts. It differs from most other genera in the absence of the preparietal bone. It has lost the postfrontal, and the prefrontal is very small. The postorbital, on the other hand, is of very large size. The palate is typically Dicynodont.

Anthodon.

In Owen's Catalogue three specimens are described under the name *Anthodon serrarius*, and all are said to come from "Bushman's River, halfway between Graham's Town and Port Elizabeth, in a marine formation containing teeth of fish, liassic shells, and fossil trees in great quantity." The type specimen consists of a badly crushed and imperfect skull; the second specimen is a jaw fragment with teeth. In Lydekker's Catalogue the skull is said to have come from naar Styl-Krantz, Sneeuwberg Range, Owen's locality being stated to be incorrect. The jaw fragment, however, is given as coming from Bushman's River. As the beds at Styl-Krantz are of Permian Age, and those at Bushman's River Lower Cretaceous, it is pretty certain that there is some mistake somewhere. A re-examination of the specimens seems to me to clear up the confusion.

The skull is evidently that of a small Pareiasaurian, and doubtless rightly referred to the Styl-Krantz horizon. It is too imperfect and too badly crushed to be quite certain of its relationships. It seems, however, just possible it may prove to be a young *Propappus*, but in the meantime it must be kept distinct.

The jaw fragment with teeth seems to me to be entirely distinct and to have nothing whatever to do with *Anthodon*. The teeth have admittedly some superficial resemblance to those of *Anthodon*, but are really very different. In *Anthodon*, as in other Pareiasaurians, the cusps are subequal and the outer side of the tooth is apparently fairly uniformly rounded. In the teeth of the Bushman's River specimen the central cusp is much the larger and there is a very large basal thickening. The manner in which the teeth are being replaced is also unlike that of the Pareiasaurians. From the Bushman River beds being Cretaceous it may be regarded as practically impossible that the teeth can be those of a Pareiasaurian, as there is no evidence that any Pareiasaurian survived the Permian. But when we compare the teeth with those of Cretaceous reptiles of other parts we find that they are strikingly similar to those of some herbivorous Dinosaurs. The teeth of *Stegosaurus* are not unlike the Bushman River teeth, but those of *Palæoscincus costatus* agree so closely as to render it highly probable that the African teeth belong to this genus. I therefore think it advisable provisionally to name the Bushman River specimen *Palæoscincus africanus*. They are manifestly not *Anthodon serrarius* and pretty certainly Dinosaurian.

Saurosternon.

Saurosternon baini is represented in the British Museum by two specimens, neither of which is very satisfactory, and hence little has been known with certainty as to the affinities of the genus. On examining the type I was able to recognise distinctly a precoracoid and coracoid of a type very similar to that of *Procolophon*, and though the head is not well preserved, it agrees, so far as can be seen, closely with *Procolophon*. There is therefore, I think, little doubt that *Saurosternon* must be placed with *Telerpeton* in the *Procolophonia*.

The horizon of *Saurosternon* probably extend from the *Endothiodon* beds to the *Lystrosaurus* beds, though it is very doubtful if the same species is found in each bed.

THE OVULE OF THE *BRUNIACEÆ*.

By W. T. Saxton, M.A., F.L.S.

(Communicated by L. Péringuey, F.R.S.S.Af.)

(Read March 16, 1910.)

Introduction.

In a recent essay by Schönland (**3**) the *Bruniaceæ* are mentioned as one of the more ancient constituents of the South African Flora. The author remarks: "The *Bruniaceæ* . . . are so isolated amongst Saxifrageæ that we can also only point to their antiquity." It seemed, therefore, desirable that an investigation of the structure of the ovule and embryo-sac should be undertaken.

The family is endemic in South Africa, and out of the 12 genera 4 are represented in the Cape Peninsula, *i.e.*, *Brunia*, *Berzelia*, *Staavia*, *Audouinia*. Fortunately, these well illustrate the range of types met with in the order, and it is very unlikely that any other genus would differ widely from these four. One species of each genus has been investigated, and the structure has been found to be very constant throughout. The primary object of the research was the investigation of the structure of the mature ovule, but it was necessary to study certain phases of development in order to explain the mature structure, and these are therefore included in the present account. The methods used have been those usually employed in cytological work, the fixing agents used having been (i.) chromacetic acid—1·5 grams chromic oxide, 7 c.c. acetic acid, 250 c.c. water; (ii.) picric, acetic, corrosive sublimate solution. The latter was found the most satisfactory.

An exceedingly accurate account of the position and external characters of the ovule in the genera investigated is given by Bentham and Hooker (**1**). In *Berzelia* the ovary is unilocular and there is only a single pendulous, anatropous ovule. In *Staavia* and *Brunia* the ovary is bilocular, in the former genus with one ovule in each loculus, in *Brunia nodiflora* with two. In *Audouinia* the ovary is trilocular with two ovules

in each loculus. In all cases the ovary is inferior or half inferior, and the ovules are pendulous and anatropous with a dorsal raphe. The foregoing description, while based on a study of the plants, is merely a repetition of that given by BENTHAM and HOOKER (*loc. cit.*), and is inserted as an introduction to the study of the ovule.

DESCRIPTION.

In each of the four genera mentioned the young ovule (at about the time of megasporogenesis) consists of a small nucellus with rather large cells and a single massive integument with somewhat smaller cells and a very long and slender micropyle. The contents of the nucellus cells are scanty, but those of the cells of the integument fairly dense (Fig. 2). It may be mentioned that in earlier stages, when the rudimentary integument first appears, there is never any indication of two integuments which subsequently fuse. If, therefore, the single integument really represents two integuments fused, it is necessary to assume that congenital fusion has occurred. In the writer's opinion such an assumption would require strong evidence to support it, which, in the present instance, is not the case. The order is (as pointed out above) so isolated, and its relationship so obscure that even a comparison with the ovule in other orders of the *Rosales* in this respect would scarcely be profitable.

The megaspore mother cell becomes much longer than its neighbours, and is separated from the apex of the nucellus by about two cells.

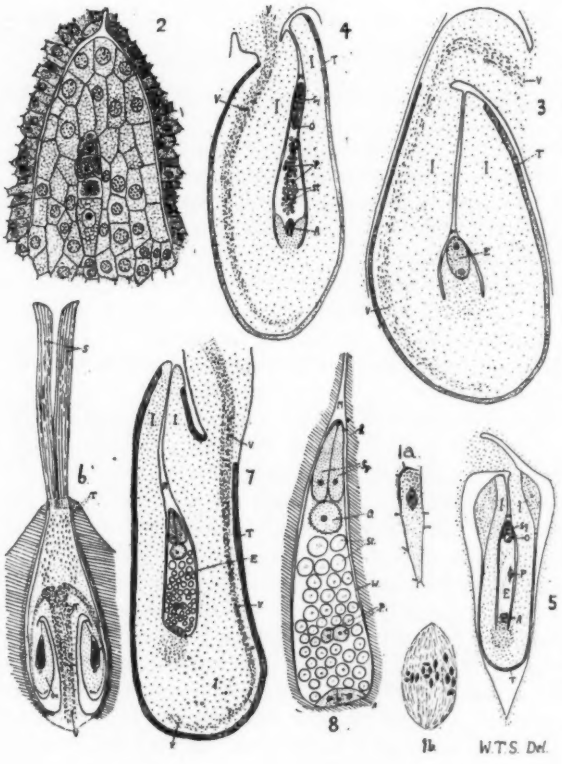
The heterotypic division has been seen, but owing to the very small size of the nuclei it was difficult to be certain of the number of chromosomes. Figs. 1*a* and 1*b* show respectively the general appearance of the mother cell, and the chromosomes of the heterotypic division, of which there appear to be 16 (*i.e.*, 8 to each daughter nucleus). In sporophytic divisions it has been quite impossible to attempt a count of chromosomes.

The divisions of the mother cell result in the usual row of four megaspores, of which the lowest becomes the embryo sac (Fig. 2). Attention was paid to this point as it is not uncommon in the *Rosales* (at least, in *Leguminosæ* and *Rosaceæ*) for one of the other megaspores to be functional. A case of this kind was recorded by the writer in *Cassia* (**2**)*. Such cases are, however, very exceptional, and while the presence of so pronounced a peculiarity would have undoubtedly indicated a close relationship to other *Rosales*, its absence cannot be regarded as evidence to the contrary.

The young embryo sac very rapidly grows upwards, absorbing the cells above it, and before the second nuclear division in the sac it has reached the apex of the nucellus (Fig. 3).

* References to other cases will be found in the paper cited.

Unfortunately, no later stage than this was obtained in *Audouinia*, but there is every indication that the mature structure would be similar to the other three genera. In these the further development results in the more or less complete absorption of the nucellus. The amount of nucellar tissue which remains in the mature ovule at the base of the embryo-sac



seems to vary inversely with the number of ovules in the ovary. In *Berzelia* (one ovule) a considerable proportion of the base of the nucellus remains (Fig. 4), in *Staavia* (2 ovules) a very small part remains (Fig. 5), whereas in *Brunia* (4 ovules) the whole of the nucellus disappears (Figs. 6, 7, 8).

The nuclear structure of the mature sac is perfectly normal: 2 pyriform synergids, a spherical egg cell, 2 polar nuclei, fusing before

fertilisation, and 3 antipodals which are not persistent. The most striking feature of the embryo-sac in *Brunia* is that it is completely filled with large starch grains (Figs. 6–8). I know of no other instance where an embryo-sac is packed with starch grains as it is in this plant. Starch grains are present also in *Berzelia*, but much smaller and not filling the sac (Fig. 4). They are apparently absent from the embryo-sac of *Staavia* (Fig. 5).*

Summary and Conclusions.

The main points of the above account may be briefly summarised as follows:—

The ovule of the *Bruniaceæ* is pendulous and anatropous, with a dorsal raphe. There is a single massive integument with a long slender micropyle. In *Brunia* the embryo-sac is packed with starch and is all that remains of the nucellus. In *Berzelia* and *Staavia* a little of the basal nucellar tissue persists.

In development the megaspore mother cell is about the third cell from the apex of the small nucellus. The usual row of four megaspores develops, of which the lowest becomes functional.

The developing embryo-sac very soon absorbs the tissues above it, and so reaches the apex of the nucellus.

The only conclusion to be drawn from this study is the same to which Schönland (*loc. cit.*) was led—namely that the *Bruniaceæ* are very isolated in the cohort to which they are usually attached. Whether the characters of the ovule also point to its antiquity may perhaps be questioned. The single integument might be regarded as a primitive character, if it were not associated with the ovule of the *Compositæ*, while in some of those orders generally regarded as primitive (*e.g.*, *Proteaceæ*) two integuments are found. Possibly the word "antiquity" was not used by Schönland in a philogenetic sense, but antiquity in the South African Flora must (if we accept the author's conclusions), imply also phylogenetic antiquity.

The other characters of the ovule rather tend to agree with essentially modern types (*e.g.*, *Compositæ*), than with primitive (*e.g.*, *Ranunculaceæ*).

In conclusion, I am glad to take this opportunity of thanking Mr. E. P. Phillips, who accompanied me on a collecting trip, and whose intimate acquaintance with the local flora was of great assistance in obtaining the requisite material for this study.

* Since the above was written, Miss E. L. Stephens has kindly shown me some slides of the embryo-sac of *Brunia*, in which she has demonstrated that the starch almost completely disappears before fertilisation. She has also drawn my attention to a paper by D'Hubert (D'Hubert, E., Recherches sur le sac embryonnaire des plantes grasses, Ann. Sci. Nat. Bot., viii. **2**: 37–128, pls. 1–3, fig. 66, 1896), in which a similar formation and subsequent absorption of starch is noted in various fleshy plants.

LITERATURE CITED.

Citations of papers not available to the writer have purposely been omitted. The more important are given in COULTER and CHAMBERLAIN'S "Morphology of Angiosperms," 1903.

1. BENTHAM, G., and HOOKER, J. D., "*Genera plantarum.*" London. 1842.

2. SAXTON, W. T., "On the Development of the Ovule and Embryo-sac in *Cassia tomentosa*, Lamk." *Trans. S. A. Phil. Soc.*, **18**: 1–5, pls. 1, 2, 1907.

3. SCHÖNLAND, S., "A Study of some Facts and Theories bearing upon the Question of the Origin of the Angiospermous Flora of South Africa." *Trans. S. A. Phil. Soc.*, **18**: 321–367. 1907.

EXPLANATION OF FIGURES.

Sections were cut with a rocking microtome, and drawings made with a Zeiss microscope, lenses, and camera lucida. Except Figs. 1 and 2 the drawings are made from more than one section of a series. They are, however, accurately drawn to scale. In all: A = Antipodals. E = Embryo-sac. I = Integument. M = Micropyle. O = Oosphere. Ov = Ovule. P = Polar nuclei. S = Style. St = Starch grains. Sy = Synergids. T = Tannin (?) containing cells. V = Vascular bundle.

FIG.

1*a*. Megaspore mother cell dividing *Staavia glutinosa*, Thunb. × 270.

1*b*. Spindle of Fig. 1*a*. × 1000.

2. Row of 4 megaspores in nucellus and a few cells of the integument. *Audouinia capitata*, Brongn. × 360.

3. Ovule with bi-nucleate embryo-sac. *Audouinia capitata*, Brongn. × 90.

4. Mature ovule of *Berzelia languinosa*, Brongn. × 75.

5. Mature ovule of *Staavia glutinosa*, Thunb. × 40.

6. Diagrammatic longitudinal section of the ovary of *Brunia nodiflora*, Linn. × 17.

7. Mature ovule of *Brunia nodiflora*, Linn. × 75.

8. Embryo-sac of *Brunia nodiflora*, Linn. × 155.

SOME NEW SOUTH AFRICAN SUCCULENTS. PART III.*

BY R. MARLOTH, PH.D., M.A., F.R.S.S.Af.

(PLATE I.)

(Read March 16, 1910.)

CRASSULACEÆ.

COTYLEDON NANA, spec. nov. (Sect. *Spicatæ.*)

Acaulis vel subacaulis. Radix tuberosa. Folia plerumque radicalia, crassa, cuneato-ovalia, superne sub-caniculata, subtus convexa, purpurea. Pedunculus 10–15 cm. altus; inflorescentia dichotomo-cymosa, pauciflora. Flores breviter stipitati, erecti, tubulosi, tubo cylindrico, sub-inflato; limbo amplo, purpureo; laciniis brevibus triangularibus radiatis demum recurvis.

Leaves 10–15 mm. long (in wild plants) and 5–8 mm. broad, fleshy, about half as thick as broad, concave or grooved in the centre, sometimes speckled with purple above. In cultivated plants the leaves are more elongate and not purple underneath. Peduncle red, the terminal inflorescence branching dichotomously, bearing 3 to 5 flowers. Pedicels short, gradually passing into the conical calyx-tube, the combined length being 10–12 mm. Teeth of calyx lanceolate, 2 mm. long, appressed to the corolla. Tube of the corolla yellowish green, slightly inflated in the upper third, 12 mm. long; the limb deep purple, rotate at first, then recurved, the segments forming about two-thirds of the limb, shaped like an equal-sided triangle, 3 mm. long. Anthers of upper stamens just reaching the mouth of the tube, the other stamens much shorter and their anthers smaller. Carpels 5; squamæ cuneate-elongate, greenish. Follicles 5, very pointed, 8 mm. long.

The plant would agree with Burchell's description of *C. parvula*, with the exception of the statement "pedicels capillary," as these are short and stout in our plant.

* Part I. in Transactions of the South African Philosophical Society, vol. xviii., 1907. Part II. in Transactions of the Royal Society of South Africa, vol. i., p. 403, 1909.

Between stones on the slopes of the Nieuwveld Mountains near Beaufort West. Flowering in January. Altitude: 1,200 m. Marloth, No. 4689.

AIZOACEÆ.

MESEMBRIANTHEMUM DESERTICOLUM, spec. nov. (Sect. 42 *Cymbiformia.*)

Planta depressa, suffruticosa, paullum ramosa, foliis subalbidis, basi connatis, trigono-inflatis, ovoideis, obtusis, marginibus rotundis. Flores terminales solitarii, breviter stipitati. Sepala 4, inæqualia; petala linearia, alba; styli 5–6.

Plant depressed, forming lumps a few inches in diam., often a few slightly elongated branches spreading on the ground. Leaves nearly egg-shaped, but slightly prismatic, the three faces convex, the angles very rounded, especially the lower one, which may be hardly indicated. Epidermis smooth, white (in the wild plant). In cultivation the new leaves are more elongated and green.

Near *M. trichotomum*, Thunb., but leaves much larger, 12–16 mm. long.

On rocky ground near Angra Pequena, in Great Namaqualand. Flowering in September. Marloth, No. 4688. (See Fig. 5.)

MESEMBRIANTHEMUM MARLOTHII, Pax. (Amended description.) Sect. *Rostellata* (Berger, p. 115).

The original diagnosis of this species was based on sterile specimens collected in 1886 by the author (Engler's Botan. Jahrb., 1888, vol. x., p. 13).

Flowers solitary, terminal, sessile, supported by two leaves, which are fringed like the others. Sepals 5, fringed like the leaves, obovate, pointed; petals white, numerous, connate at base, linear, recurving above, the upright part being 7 mm., the recurved portion 3 mm. long. Stamens 15–20; stigmas 5.

Very frequent on rocky as well as sandy ground in the littoral belt (Namib) of Great Namaqualand. Flowering in spring. Marloth, No. 4676.

The fringe of hairs around the apex of the older leaves originates in a peculiar way. The young leaves are shortly cylindrical and surrounded at their upper third by a ring of retrorse, fully turgescent hairs, which may be looked upon as elongated papillæ, pointing downwards. Later on the apex of the leaf shrivels and leaves the fringe of hairs on the leaf in organic connection with the remaining part. The origin and structure of these hairs indicate that they assist in the absorption of dew and water

from fogs. This ability of the plant probably accounts for its universal occurrence in the desert, even in localities where no other permanent vegetation exists.

MESEMBRIANTHEMUM NAMIBENSE, spec. nov. (Sect. *Rostellata.*)

Suffrutex pedalis, ramosissimus. Folia in ramulis junioribus ovali-trigona, obtusa, papulosa, basi connata; in adultis ad spinas breves reducta. Flores terminales, solitarii, sessiles ex centro foliorum apicalium; sepala 5, cylindrico-elongata, obtusa, papulosa, non-fimbriata. Petala alba, linearia, basi connata, sepala haud superantia; stamina 15–20; styli 5, filiformes.

A hemispherical shrublet, from a few inches to a foot or more in diam. In summer dark in colour, with no sign of green, as the leaves have dropped off. The young shoots appear in winter and spring, bearing several pairs of 3-edged, ovate, blunt leaves, joined at their base, mostly green, but often reddish. Later on the leaves shrivel up, while the internodes between the pairs increase in length and diam., each joint retaining the remains of the two leaves as two oppositely standing little spines. The branches have a slightly moniliform appearance, but not as distinctly as in *M. moniliforme*. The development of the leaves into spines is somewhat similar to that of *M. Marlothii*, with which this species has been confused up to the present, as it grows intermingled with it and resembles it somewhat, at least in summer. In that species, however, the leaves themselves form the joints, which slightly sheath over another, their apex only shrivelling and remaining as mucro, while the upper margin of the joined pair of leaves remains covered with a fringe of long white hairs absent in *M. namibense*.

The same difference occurs in the sepals of the flower. They are similar to the leaves, viz., blunt and without a fringe, while in the other species they bear a mucro and are amply fringed.

Leaves of the young shoots (free portion) 3–4 mm., joints of adult branches 4–5 mm. long and of the same diameter. Flowers shortly tubular in shape, hardly opening, petals white, slightly recurved above the sepals; diam. of flower 6–9 mm.

Frequent in sandy soil of the Namib near the coast as well as further inland. Flowering at Angra Pequena in September. Marloth, No. 4686.

MESEMBRIANTHEMUM MITRATUM, spec. nov. Sub-genus TRIQUETRA. (New Sect. *Mitrata.*)

Suffrutex pedalis, ramis erectis, angulatis. Folia dua in apice ramorum terminalia, pollicaria, basi connata, lateribus superioribus mutue adpressa, residuo membranaceo foliorum duorum præcedentium inclusa, corpuscu-

lum terminale, conico-ovoideum, mitram referens. Flos stipitatus in corpusculo inclusus, demum latere corpusculi petalis exiens. Sepala 5, papillosa, tria majora apice membranaceo-ampliata; petala numerosa, linearia; styli 4, filiformes.

A very remarkable plant. Each branch terminates in a leaf-body, formed by one pair of leaves, pressed with their upper faces against each other and sheathed completely in the papery remains of last year's leaf-body. In midsummer the sheath splits at the side and the flower-bud appears, showing its white, slightly pink petals. Sepals 5, three of them enlarged by a membranous apical edge. Flower and fruit draw food and water from the fleshy corpusculum that surrounds them, until the body finally becomes exhausted and shrivels up. When the next rain comes the bud alongside of the fruit develops a short stalk and a new corpusculum, which repeats the process the following season.

The method of protecting flower and fruit against the effects of drought is the same as we find in all the species of the section *Sphæroidea*, but owing to the production of a new internode every year, an inch or two long, a shrub is produced, the branches of which, owing to their brown corky bark, appear to be dry, but are fresh in the centre, and carry the terminal fleshy corpuscula at their ends like knobs on a stick.

In the sandy deserts about ten miles east of Port Nolloth in Little Namaqualand. Flowering in January. Collected by Mr. Garwood Alston. Marloth, No. 4690. (Fig. 4.)

EUPHORBIACEÆ.

EUPHORBIA GREGARIA, spec. nov. (Sect. *Tirucalli.*)

Frutex ramosissimus ramis rigidis, cinereo-glaucis, nudis. Cymulæ dichotomæ, 6–10, brevissime stipitatæ, ramorum apicem versus subcapitatæ. Involucrum conico-campanulatum, tomentosum, basi foliolis 2 parvis, ovatis suffultum, lobis ovato-rotundatis, fimbriatis, glandulis parvis, stipitatis, orbiculatis, latere inferiore plicatis. Capsula stipitata, depresso-sphærica, 8–10 costata, tomentosa. Semina globoso-prismatica, lævia.

The shrub is generally about 2 m. high, occasionally 3 m., and of the same diam., mostly truncate at the top. The main branches are 3–5 cm. thick, the terminal twigs of the thickness of a pencil. Cyathium small, 4–5 mm. in diam. and 2–3 mm. long. Glands brown. Fruit-stalk 10–15 mm. long, capsule large, 15 mm. in diam., tomentose, yellow when ripe. Seeds prismatic on the inner side, with a deep furrow on the central ridge, smooth, white, 8 mm. long and 6 mm. in diam.

The species is very similar in habit and appearance to *E. gummifera* Boissier, but differs from it in its involucre, glands, and fruits. Just as *E. gummifera* is the dominating plant in some parts of the Namib, *e.g.*, near Tschaukaib, this species determines the character of the landscape over a considerable portion of the interior of Great Namaqualand, especially in the country between the Little Karas Mountains, the lower Fish River and the Orange River. Marloth, No. 4683. (See Fig. 7.)

EUPHORBIA ELASTICA, spec. nov. (Sect. *Tirucalli.*)

Frutex ramosissimus habitu *E. mauritanicæ*, ramis striatis, cinereo-pulverulentis, ramulis brevibus, rigidis, erectis. Folia nulla vel decidua. Cyathia pedunculata in cymulis paucifloribus aggregata, basi foliolis 2 magnis, rotundis, concavis, mucronatis, cyathio sublongioribus suffulta. Involucrum campanulatum lobis ovatis, fimbriatis, glandulis concavo-spathulatis, truncatis, apice crenulatis, basi margine involuto angustatis, extus hirtis. Ovarium stipitatum, globosum, hirtum.

A nearly spherical or somewhat egg-shaped shrub, 1–2 m. high, much branched from the base, the main branches 2–3 cm. in diam. Apparently leafless, the surface of the branches grey, covered with a whitish powder. The inflorescence on short lateral branchlets, 3-headed, the central cyathium sessile, the lateral ones stipitate, the stalk being 10–12 mm. long. Bracts 2, large, concave, almost enclosing the cyathium, each 8–10 mm. wide. Involucre and glands hairy on the outer side, the lobes ovate and fimbriate; glands brown, curving upwards from a horizontal, narrow, clawlike, basal portion, the apex truncate and wavy.

In habit the plant resembles other members of the section *Tirucalli*, but the cyathia are more like those of *E. cervicornis*. (Sect. *Treisia.*)

Little Namaqualand, near Anenous, between Port Nolloth and the higher interior, covering wide stretches of country. Marloth, 4684.

The milky juice has been used for the manufacture of rubber, but it contains much resinous matter.

EUPHORBIA HYPOGÆA, spec. nov. (Sect. *Medusea.*)

Radix napiformis. Caules plures e summo radicis, subterranei. Rami breves. 1–3, cylindracei, podariis numerosis elongatis. Folia linearia, caduca, 5–8 mm. longa. Cyathia pedicellata, erecta, solitaria vel 2–3; involucrum campanulatum segmentis fimbriatis, glandulis lunatis viridibus.

Root and main branches are underground, the short branchlets only appearing above the surface. The tubercles are elongated, nearly as long as the branch is thick, viz.: 4–5 mm., the total diam. of the branch being

about 15 mm. Leaves are present during the rainy season and about ¼ inch long. The cyathia stand erect on peduncles which are 10 to 20 mm. long, either solitary or 2 to 3 together on the same branch. Involucre greenish red, the segments white, fimbriate; anthers dark red. The glands are dark green, shaped like the moon when about one-third full, the two horns projecting outwards. Capsule the size of a pea. Branchlets about 1–2 inches long.

In clayey soil on the Nieuwveld near Beaufort West. Altitude 1,300 m. Flowering in November. Marloth, No. 4692. (Figs. 2 and 3.)

EUPHORBIA FUSCA, spec. nov. (Sect. *Medusea.*)

Planta acaulis habitu *E. Caput Medusæ*, ramis brevibus digiti-formibus, aphyllis. Cyathia breviter stipitata, pedunculis non-persistentibus. Involucri segmenta lato-cuneata, fimbriata, fusca. Glanduli fusci, 4–5 dentati, dentibus linearibus, albidis, rariter apice bipartitis.

In habit just like *E. Caput Medusæ* with an almost globular central caudex, from which the short, finger-like branches radiate. Easily distinguished from *E. Caput Medusæ* by the smaller size and brown colour of the glands and involucre, from *E. anacantha* by the stipitate flowers, and from *E. crassipes* by the non-persistent peduncles.

Kimberley, Steynsburg, Britstown. Altitude 1,200–1,300 mm. Flowering November. Marloth, No. 4682.

COMPOSITÆ.

OTHONNA CLAVIFOLIA, spec. nov. (Sect. *Carnosæ.*)

Caulis brevis, crassus, simplex, napiformis vel parum ramosus, ramis brevissimis. Folia pauca, carnosa, ovoidea vel clavata, apicibus ramorum aggregata. Pedunculi ex apicibus ramorum, simplices. Capitula radiata. Achenia canescentia.

The short caudex is embedded in the ground or between the gravel of fissures in the rocks 1–2 inches high, with or without a few stout, short branches. The leaves are alternate, very fleshy, either shortly club-shaped, 10–15 mm. long and half as wide, or, as in cultivated specimens, more elongate, up to 30 mm. long and 6–8 mm. in diam. in the upper part. Reddish glaucous on the wild plants, often the interior quite red as well. Scapes one-flowered, 1–2 inches long; involucre of 6–8 free, narrow-oblong, mucronate bracts, brownish green with white edges; no calycle. Rays yellow, twice as long as the involucre. Achenes oblong, curved, narrowed at both ends, canescent from closely appressed, short hairs.

Pappus white, bristles stiff and rough. Near *O. sedifolia* DC., but achenes not glabrous.

In crevices of rocks near Angra Pequena, flowering in winter and spring. Marloth, 4691. (See Fig. 1.)

LILIACEÆ.

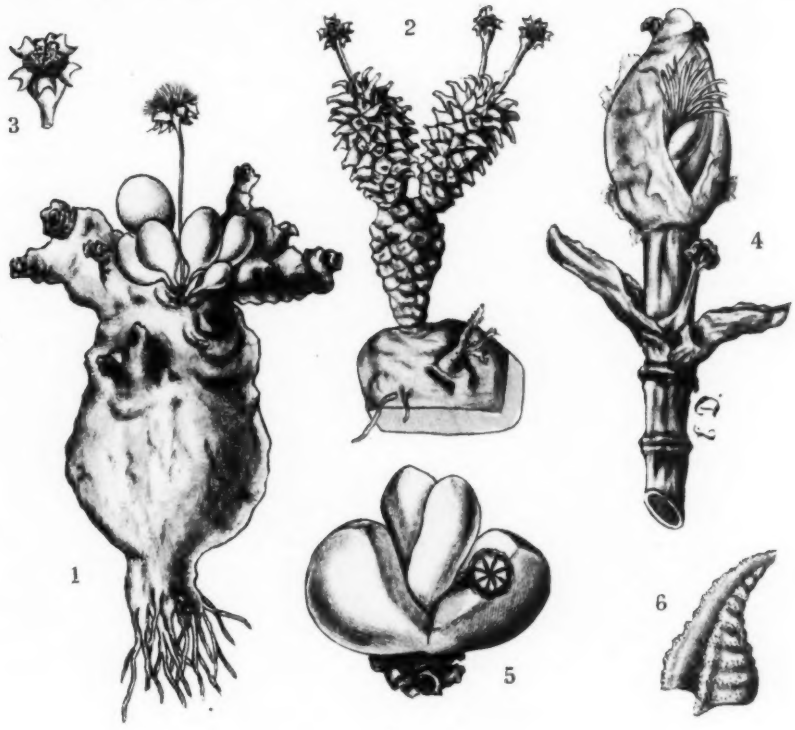
HAWORTHIA GRANULATA, spec. nov. (Sect. *Scabræ.*)

Acaulis, e basi prolifera et cæspitosa. Folia parum numerosa, spiralia, sub-patentia, carnosa, rigida, ovato-lanceolata, breviter acuminata, supra concava et lævia, subtus valde convexa, cinereo-viridia, tuberculis minutis concoloribus creberrime transverse subseriatis rugosa. Pedunculus gracilis, pauciflorus; flores breviter pedicellati, minutissime bracteati, perigonio obclavato, bilabiato, viridi-albido, roseo-striato, segmentis revolutis, albidis, rubro-carinatis.

The plant is in habit, inflorescence, and flowers similar to *Haworthia scabra* Haw., but the leaves are smooth on the upper face and the tubercles on the lower side, although closely adjoining each other, are not confluent.

Rosette of leaves 30–40 mm. in diam.; leaves 20–30 mm. long, 10–15 mm. broad; peduncle 15–20 cm. high, pedicels 3 mm.; perianth-tube 10 mm., the free limb 5–6 mm.

On slaty rocks of the escarpment of the Roggeveld Mountains in Verlaten Kloof, 1,300 m. Flowering in December. Marloth, No. 4217. (See Fig. 6.)



West, Newman proc.

NEW SOUTH AFRICAN SUCCULENTS.

1. Othonna clavifolia, *Marloth* (nat. size). 2. Euphorbia hypogæa, *Marl.* (branch cut off from rhizome). 3. Cyathium of same (enlarged × 2). 4. Mesembrianthemum mitratum, *Marl.* (piece of a branch, nat. size). 5. Mesembrianthemum deserticolum, *Marl.* (branch, nat. size). 6. Haworthia granulata, *Marl.* (leaf, nat. size). 7. Euphorbia gregaria, *Marl.* (near the Lower Fish River in Great Namaqualand; bush 3 m. high).

ON *CHRYSOCHLORIS NAMAQUENSIS*, Broom.

By R. Broom, M.D., D.Sc., F.R.S.S.Af.

(Read March 16, 1910.)

When in Namaqualand thirteen years ago I made at Garies a collection of the skulls of small mammals from the disgorged pellets of owls. Among them I believed I had discovered the skulls of three new species of *Chrysochloris*, which in the Annals and Magazine of Natural History for February, 1907, I named as *C. granti*, *C. namaquensis*, and *C. tenuis*. A fuller description was afterwards published in the Transactions of the South African Philosophical Society, vol. xviii., pt. 3. Of *C. granti* I was fortunate in discovering a skin in the South African Museum. Besides being the smallest known species it differs from all others in having long fur and in having the 4th claw of the front foot well developed. *C. namaquensis* and *C. tenuis* agreed with each other pretty closely, except that the former has 40 teeth and the latter only 36. As only the skulls were known, I have been endeavouring for some time to get skins, and have at last been successful.

From Mrs. Thomas Dixon, of Roodeberg Kloof, near Garies, I have obtained a spirit specimen of a young female of *C. namaquensis*. Though badly preserved, owing to the spirit having been too weak, it is possible now to give a complete description of both the skin and the skull.

The nose-pad measures 9·5 mm. in width and resembles that of *C. asiatica* in having the outer corners pointed.

The fur over the back is light brownish grey, the deeper fur being pale slate. On the abdomen and breast the terminal parts of the hairs are much lighter. Round the lips and down the chin the hairs are short and of a pale creamy-yellow colour. On the cheeks and top of the head the yellow hairs are continued, but over the forehead, the nasal region, and especially behind the outer angles of the nose-pad, the hairs are tipped with brown, so that there is little difference in colour between the frontal region and the dorsal, except that the former has a yellow under-fur and

the latter a slate. In the region of the eyes the brown tips are very slightly marked, so that the whole ocular region may be described as creamy-yellow.

In general size *C. namaquensis* is a little smaller than *C. asiatica*, the present specimen measuring in greatest length 100 mm., and the hind foot 10 mm.

The claws of the front foot measure: 1st, 2·5; 2nd, 5; 3rd, 10·5; and 4th, 1 mm.

The skull in greatest length measures 21·8 mm.; in greatest width 16·2 mm.; and in greatest height 11 mm. The orbital region measures 6·4 across. The dental series measures 9 and 8·5, the molar series 5. The palatal width is 7·6 mm.

Though the temporal bulla is well formed, it is considerably smaller than in *C. asiatica*.

The upper teeth on the whole are fairly like those of *C. asiatica*. The 1st incisors are large and of the ordinary type, and the 2nd incisor is also of the type seen in the better-known species. The 3rd incisor is very small, having less than half the antero-posterior length of the 2nd incisor and only about half its height. It is a small, rounded, simple cone with no ridges or cusps. The canine is nearly as large as the 2nd incisor, and has a sharp posterior edge, giving the top a triangular appearance, which suggests the beginning of the molariform type of *C. obtusirostris*. The 1st premolar represents only a further development of the condition seen in the canine, and shows a triangular crown with no trace of the internal cusp seen in *C. villosa*. The 2nd and 3rd premolars and the 1st and 2nd true molars are of the well-known type with small but well-marked internal cusps or protocones. The 3rd molar is the most remarkable feature of the skull, as it is apparently absent or present in about equal frequency. When present it is rudimentary and has only a single small median cusp.

The lower teeth are also much like those of *C. asiatica*. The premolars and molars have completely lost the talonids with the exception of the 2nd premolar, where there is a slight rudimentary projection which represents it. The 3rd molar, though small, is quite well formed.

By Thomas and others all those Golden Moles which have only 36 teeth are placed in the distinct genus *Amblysomus*. In my recent paper I have argued that the difference between such a species as *C. hottentota*, which has lost the last molar, and *C. sclateri*, in which it is rudimentary, is so very little that it seemed to me unwise to place the forms with only 2 molars in a different genus. The condition of the last molar in *C. namaquensis* further confirms the view I expressed. Out of 7 skulls which I have examined 3 have 10 teeth on both sides, 2 have 9 teeth on both sides,

and 2 have 10 on the one side and 9 on the other. It was those skulls with 9 teeth on each side on which I founded the species *C. tenuis*. This it is now manifest becomes a synonym of *C. namaquensis*. If the same species in the same locality can have either 9 or 10 teeth, and some specimens have 9 on the one side and 10 on the other side of the skull, it becomes quite impossible to establish the separate genus *Amblysomus* for those moles with 9 teeth.

ROYAL SOCIETY OF SOUTH AFRICA.

PRESIDENT'S ADDRESS.

By S. S. HOUGH, M.A., F.R.S., F.R.S.S.Af.

(Read April 20, 1910.)

It is four years since an address has been delivered from this chair, and it is fitting that I should commence by supplementing the reports you have just heard from the Secretary and Treasurer by a short reference to the history of our Society during those four years.

It will be remembered that the members of the South African Philosophical Society, with a growing feeling that the general usefulness and standing of the Society might be thereby advanced, had, following the example of similar Societies in other Colonies, petitioned His Majesty for a Charter of Incorporation, under the title of the Royal Society of South Africa.

Objections were raised to the granting of this Charter by representatives of other South African Societies, and as a consequence, at the instance of Lord Milner, the petition was temporarily withdrawn, while negotiations were entered into with a view to arriving at some mutual understanding.

The general outcome of these negotiations was that the previous objections were referred to a committee, accepted by all concerned as representative of the highest scientific interests in South Africa, who were instructed to prepare a draft constitution, which, in the light of these negotiations, might prove of general acceptance.

The committee after much consultation arrived at a draft constitution which fulfilled these conditions; the original objections were withdrawn, and the petition of the South African Philosophical Society, with certain modifications, designed to secure fuller representation on its Executive of the best interests of science throughout the whole of South Africa, was proceeded with.

On the 27th of February, 1908, the Secretary was in a position to

announce to the Council that this petition had been favourably considered by His Majesty in Council, and that a Charter of Incorporation, under the Statutes drafted by the Committee, had been duly received.

Henceforward the Society entered on a new phase of life under its new style of The Royal Society of South Africa, and now that it is fairly launched in its new career we may look forward with confidence to a future of increased usefulness.

I pass now to the main subject of my address to-night, which I propose to entitle—

Some of the Aims of Astronomy of Precision.

The Cape Observatory was established by Order in Council, dated October 20, 1820, as the outcome of a resolution by the Board of Longitude to the effect—

> . . . "That it would be highly conducive to the improvement of practical astronomy and navigation that a permanent Observatory should be established at the Cape of Good Hope, which would afford a series of comparative observations made under circumstances the most favourable for correcting the unavoidable imperfections depending on the instruments employed and on the materials surrounding them by a countervailing tendency to equal and opposite errors." . . .

As is natural under these circumstances that branch of astronomy known as astronomy of precision, viz., that which depends on the most precise geometrical measurement has always formed the principal item of the work of the establishment, and it has been the aim of successive astronomers not merely to maintain, but to advance the accuracy of the observations for which they have been responsible.

The science of precise physical measurement is one which does not readily appeal to those not immediately concerned, either with the methods or results. An authoritative statement that the sun's distance from the earth is 92,880,000 miles may excite wonder, but scarcely more than will the statement that it is approximately 93,000,000, except in the minds of those who are in some measure acquainted with the laborious processes by which the two extra figures are derived. In fact, I have not infrequently heard the methods of observation used described by some such epithet as "hair-splitting." For this reason I think I cannot do better to-night than to describe to you, without entering into technical details of the methods employed, some of the aims and objects to which modern astronomy of precision is devoted, and which render essential none but the highest refinements that human ingenuity can devise.

Perhaps the primary reason why astronomy appeals to the popular

imagination in a higher degree than other sciences is that astronomy is *par excellence* the science of prediction. True, the days are now past when an astronomer is regarded, except by the most ignorant, as gifted with supernatural powers and capable of predicting events that can have no conceivable relationship with the objects of his researches, or when an unscrupulous astronomer could utilise his powers of prediction for imposing on the world at large in the face of the criticisms of fellow-workers in collateral branches of science. Nevertheless it is only necessary to point to any of the leading almanacs to establish the undoubted claim of astronomy to a considerable predictive capacity in its own legitimate sphere. These almanacs, prepared in advance, give from day to day the positions of the sun and moon, the phenomena of eclipses and various other data with an accuracy which can only be called in question by the most refined tests available to astronomers.

How, then, has astronomy acquired this faculty? The answer to this question is—at least primarily—by continuous and patient observation, using always the most refined methods of physical measurement available.

A well-devised scheme of observation is sooner or later bound to lead to the detection of laws governing physical phenomena if such laws exist. Thus it was the planetary observations of Tycho Brahe which led to the detection of the laws of planetary motion associated with the name of Kepler.

Once such laws have been established and the necessary initial data secured, the science of astronomical prediction would for the future devolve on the mathematician rather than the astronomer, were it not for two sources of uncertainty with which the astronomer must continue to concern himself. It is evident, on the one hand, that we cannot infuse into our predicted phenomena greater precision than that derived from the initial data, themselves dependent on imperfect observations. However well the laws governing planetary motions may be understood, the predicted position of a planet to-day depends on its observed positions at some earlier epoch or epochs; and the fallibility of the observations made at these earlier epochs will not only pervade all future predictions, but will inevitably increase in amount as the epoch of prediction recedes from the epoch of observation. For this reason, if the standard of accuracy of prediction is to be merely maintained—and the growing requirements of science will scarcely rest contented with this—continuous observation must be maintained and the data on which predictions are based revised from time to time.

I have dealt so far only with the effects of the unavoidable inaccuracies of observations, even when pushed to their utmost refinement, as influencing results of prediction. A second consideration of even greater importance is the validity of the laws associating the predicted with the

observed phenomena. I may illustrate my point again by reference to the laws of Kepler. It is now well known that these laws are only rough approximations to the actual truth, and that though they might serve as a useful basis for prediction over a short interval, a few years at most would suffice by showing a rapidly increasing departure between the observed and predicted positions of the planets to indicate that these laws require amendment.

That the direction this amendment should take followed so soon on the original discovery of Kepler's laws, was due to the genius of Newton, who showed that the theory of universal gravitation propounded by him not only adequately accounted for the laws enunciated by Kepler, and pointed to their imperfections, but served to co-ordinate as due to a single cause even more recondite phenomena such as the leading inequalities in the motion of the moon, the precessional motion of the earth, and the phenomena of the tides. This theory further reduced to order those astronomical vagaries the comets, showing that, so long at least as they remained within the precincts of the solar system, their motions were governed by it, while observations of double stars have established beyond question that even remote parts of the universe are still subject to the same laws.

The dynamical laws propounded by Newton, which to-day virtually form the basis of all astronomical prediction, enable us to trace back as well as to trace forward the history of the solar system, and to confront modern observations with historical records. Needless to say, in but rare instances do these records possess the necessary elements of precision to strengthen the existing data required by the astronomer; but there are important exceptions. For instance, a very small uncertainty in the "elements," which in conjunction with Newton's laws govern the motion of the moon, will produce by lapse of time a large change in the comparatively small area of the earth's surface over which a total eclipse of the sun is visible as such. Thus, a record that a particular eclipse was seen as total in a given locality becomes an observation of precision, provided only the chronological date at which the eclipse occurred can be traced with sufficient certainty to ensure the identification of the eclipse concerned.

The confrontation of modern with historical observations of such a character has served to establish beyond question the high degree of accuracy with which the laws of Newton represent the motions within the solar system, and their reliability as a basis of prediction for years, perhaps for centuries, to come. It is, however, on various grounds quite certain that these laws in themselves are not absolute, far-reaching though they are, and that they in turn like those of Kepler must be superseded by laws still more exact.

Until such laws are discovered there will always remain an element of uncertainty apart from that due to the initial data affecting all predicted phenomena—an uncertainty which can only be removed when the phenomena cease to be prospective, and when they can be confronted with later as well as with earlier observations.

The fact, however, that the laws of gravitation yield such a close representation of the observed motions within the solar system throughout historic time, renders the detection of a departure from these laws a question of extreme delicacy, but none the less essential, if prediction is to be secured for long periods in advance.

I have dwelt at length on the importance of a study of these laws—a study which at every turn calls for more numerous, and, above all, more accurate observations. Even, however, if the laws of gravitation could be established as absolute, our capacity for prediction would be limited by the accumulation *with time* of the small sources of uncertainty affecting the original observations on which all data for prediction must be based. These sources of uncertainty may be minimised by extending our observations over a long interval. Such an extension will doubtless be possible in the future, and we may be sure that astronomers of future centuries will take advantage of the facilities which lapse of time will afford them.

At present, however, though, as I have already indicated, we can to some extent retrace the past, opportunities for verifying our theories in the light of early records and thereby strengthening our data are few and far between, and generally lacking in the necessary elements of precision required.

Exact astronomy in the modern sense only dates back for about a century and a half, during which interval, however, most of the data usually to be found in almanacs may be considered to be known at any instant with a precision that can scarcely be expected to be improved on. Where immediate direct observations are not available, these data may be derived from considerable numbers of observations taken both before and after the actual instant by the mathematical process of "interpolation" with a precision scarcely less than if all these observations were made actually at the instant under consideration, and the effects of fallibility in the actual observations themselves can be reduced to a minimum by incorporating as large a number of them as are available.

What, however, I wish to impress on you is that of necessity prediction always involves essentially the far more uncertain process of extrapolation—a process requiring for similar accuracy far higher precision in the initial data employed, more accurate knowledge of the laws by which these data may be combined and which is at all times liable to an additional source of uncertainty owing to the cumulative effect with time of sources

of error either unsuspected or undeterminable from the nature of the data employed. It is considerations such as these, which demand an incessant repetition of observations even in cases where existing knowledge might at first sight appear sufficiently secure to serve for all future time.

I have selected my illustrations largely from the solar system chiefly on the grounds that, thanks to the Newtonian laws, it is here that, in spite of the immense mathematical difficulties which have had to be faced, astronomical prediction has attained its greatest triumphs. I need scarcely mention the oft-quoted incident of the discovery of the planet Neptune, but cannot refrain at this time from directing your attention to the work of Messrs. Cowell and Crommelin in connection with the recent reappearance of Halley's comet. In spite of an interval of seventy-five years since this body was last observed, the comet was picked up on photographic plates long before it could be seen even with powerful telescopes almost in the exact position assigned by them, and we may confidently anticipate that, when their data are supplemented by those that have been and will be secured at the present apparition, its position at its next appearance will be assigned with an accuracy scarcely inferior to that of the planets at the present day.

I wish now, however, to divert your attention to the stars. In so far as these form the fiducial points to which the motions of the planets and other members of the solar system are referred, it is essential that the positions of a limited number at least should be determined with the highest possible accuracy. Any uncertainty in their positions will undoubtedly be reflected in the positions of the planets, and will constitute one of those sources of error so liable to increase with time, and render efforts at prediction if not entirely nugatory at least partially ineffective.

The universe of so-called "fixed stars" is not invariable in aspect, though its changes for the most part are of so minute a character that they can only be surely detected either by the most delicate measurements or by their cumulative effect over long intervals of time. It is chiefly through a study of these changes that our knowledge of the stellar universe has been acquired in the past, and it is largely to similar means that we look for an extension of this knowledge.

Among changes which lend themselves to observation for this purpose we may enumerate—

1. Changes of the intensity of the light of the stars. The origin of these changes except in a few instances remains obscure. In certain cases, however, notably in the case of variable stars of the Algol type, a satisfactory explanation of the observed phenomena has been found in the motions of a system, governed by laws similar to those operating in our solar system, of which the visible star forms a constituent member.

2. Changes of position due to orbital motion in binary or multiple

stars. Where both components of a binary star are visible, these changes readily admit of direct measurement. In other cases the existence of a companion is inferred to account for regular periodic changes of position of the visible component, though this companion cannot be seen either on account of intrinsic want of light, or on account of its close proximity to the primary and the consequent incapacity of our telescope to render the two visually distinct.

These changes are of interest as affording evidence of the validity of the Newtonian laws in systems other than the solar system.

The changes to which I have so far referred are changes which affect isolated stars or groups of stars, but which do not occur, at least to a sensible extent, in the generality of stars.

I come now to the changes of position due to the earth's orbital motion which, on the other hand, may be expected to influence all stars in common. Even where, as in the cases I have already spoken of, their influence is obscured by orbital motion within the system, when once this orbital motion has been thoroughly examined, its laws deduced, and due allowance made for it by computation, we might expect to find the effects of the earth's motion still apparent.

The earth in its orbit round the sun approximately describes a circle of 186,000,000 miles in diameter, and its successive positions in space at intervals of six months are separated from one another by this extent. But experience has shown that recurring changes in the relative positions of the stars, as viewed at intervals of six months—that is to say from two different points of the universe separated by this vast distance—can only be detected in the case of a limited number of stars, and then only by the application of the most delicate methods of measurement specially designed to bring these changes to light.

To the Cape Observatory and its former director, Henderson (1832–34), belongs the credit of first producing reliable evidence of the existence of any fixed star, for which these changes could be unmistakably detected, and which therefore was not too remote from the solar system to permit of its distance being at least roughly determined in comparison with the diameter of the earth's orbit. Henderson's discovery has since been fully confirmed by later observers, and other stars likely to yield tangible results have now been examined. As illustrative, however, of the evasiveness of the quantities sought, and the excessive labour by which only they can be derived, though the problem of stellar distance has always been in the forefront of astronomical interest, and has attracted the attention of several able observers, the number of stars for which well-determined parallaxes have been published up to the present day does not exceed some 400. This number is quite insignificant in comparison even with the number of stars visible to the naked eye without telescopic

aid. Moreover, the stars investigated have been in general selected on the grounds of some *a priori* probability of their possessing a measurable parallax, either on account of apparent brightness or on account of their large apparent motion; and for this reason they can scarcely be regarded as typical of the generality of stars.

In order, then, to gauge the depths of the visible universe it would appear imperative that our base-line must in some manner be extended. The distance of 186,000,000 miles, through which we are carried in the course of a single half-year by the orbital motion of our planet round the sun, is so small in comparison with interstellar distances as to give rise to changes in the apparent relative positions of stars which, except in the most pronounced instances, are so insignificant in amount as to defy detection even by the most refined processes of measurement we possess.

How, then, can such an extension of our base-line be attained? I have already pointed out that the so-called "fixed stars" are not truly "fixed," but that on close observation it is found that each star has an apparent motion either peculiar to itself or shared by other neighbouring stars which, with it, constitute an independent system. I refer primarily to the visible motion transverse to the line of sight.

If then our sun, as we may reasonably suppose, is itself a member of the stellar universe, it may be anticipated that it too will not be at rest, but will be moving forward in space, and the visible motions will be those due to the combined effects of the motion of the sun and stars.

That the apparent motions of the stars were not entirely fortuitous but that they could at least partially be co-ordinated throughout the sky as the visible manifestations of a single phenomenon, viz., a translatory motion of the sun with its system of planets through interstellar space was first pointed out by Sir William Herschel, who further indicated that the point of space to which this motion was directed was situated in the constellation "Hercules."

Before proceeding to the further consideration of this solar motion, I wish first to point out to you how its existence at once suggests a means of "extending our base-line" for the purpose of gauging these interstellar depths. I have refrained from any numerical estimates of the amount of this motion, as this involves philosophical questions into which I do not desire to enter to-night. But in order to fix our ideas it is necessary for me to give you some notion at least of the order of magnitude. It is now possible to state with some certainty that the speed of the sun's motion relatively to the stars as a whole amounts to about 20 kilometres per second, and that the space traversed in a single day therefore amounts to rather over a 1,000,000 miles, that in a year to about 400,000,000 miles. Thus the stars, as seen on two occasions a

year apart, may be considered as viewed from two points in space separated by this length, and it only requires lapse of time in order to increase the length to an almost indefinite extent.

The great scheme for the photographic mapping of the heavens at present being carried out on extensive scale by means of the co-operative efforts of the leading observatories of the world will shortly furnish a highly accurate delineation of the skies as seen at the commencement of the twentieth century. This alone has called for concentrated effort extending over some twelve years at least, while it would even now scarcely be safe to say that another ten years will see its completion. An immediate repetition is scarcely to be contemplated, though a subsequent repetition at some future epoch, which may be agreed on by astronomers, forms an essential part of the programme as originally introduced.

When this scheme is completed in its entirety very ample data will be available for the discussion of stellar distribution by the methods I have suggested to you.

In the meantime, however, in such tentative attempts as have been made to fathom the secrets of the universe by means of the study of stellar proper motion, it has been necessary to rely on early recorded exact observations. It will be clear from what I have already explained to you, that it is the earliest reliable records in comparison with the most up-to-date available which will yield the greatest length of base-line and consequently the most trustworthy results.

For this reason the majority of the discussions hitherto attempted have been based on the catalogue of Bradley, dependent on observations made by him at Greenwich between the years 1750–62.

This catalogue contains the places of some 3,000 stars observed with a precision far surpassing any similar previous observations and comparing favourably with the best modern catalogues. The stars selected by Bradley are fairly uniformly distributed over the portions of the sky accessible to him, viz., from the North Pole to 30° South of the Equator.

Unfortunately no early catalogue of stars of even approximately similar precision exists for the remaining region of the sky between 30° S. Decl. and the South Pole, and the absence of exact knowledge of these regions for the earlier epochs has always hampered these discussions.

The discussions I refer to have generally had as their immediate objective—

1. The determination of the precessional constant, *i.e.*, the annual amount by which the earth's axis of rotation changes its position in space, and—

2. The determination of the speed of the solar motion and the position

of the solar apex, *i.e.*, the point in the heavens towards which the sun's motion is directed.

The discrepancies in these quantities found by different investigators, either starting with different data or utilising different methods for the combination and discussion of the same material, had long been a puzzle to astronomers. The key to the situation was at length furnished by Professor Kapteyn, of Groningen, who, in an epoch-making paper read before the British Association in Cape Town, first pointed out that the apparent motions of the stars indicated not merely the existence of a single solar apex, but that there were two separate regions of the sky towards which a preference was shown by the directions of motion of the Bradley stars.

This was a phenomenon which could not be explained by a simple motion of translation of the sun, as evidently the sun's motion could not be directed to two different points simultaneously, and the only feasible explanation was that the stars consisted of two groups and that the motion of the sun relatively to one of these groups differed from its motion relatively to the other, or that, though the stars appeared intermingled in space, they possessed an independent relative motion, which might be regarded as located in one group or in the other, but which was shared by all the stars peculiar to the group.

The theory of the existence of two streams or drifts of stars thus put forward by Kapteyn has since received full confirmation by other investigators, notably by Eddington, who based his examination on the early observations of Groombridge, and by Dyson, who limited his discussion to a selected list of stars possessing considerable proper motions.

Recent investigations at the Cape, to which I shall refer later, have led us to examine in somewhat more minute detail the proper motions of the Bradley stars, with the result that, though the phenomena first noticed by Kapteyn stand out as the most prominent feature, certain subsidiary features of no less importance have been brought to light.

It will be clear that, if we fix our attention on stars situated in the region of the sky immediately surrounding the solar apex, the transverse motion of the stars due to the sun's own motion must vanish. The same will be true for stars situated near the antiapex or region from which the sun is receding.

The transverse motion will be greatest for stars on a zone situated half-way between these two points. In the case of a double drift, as suggested by Kapteyn, it is clear that the only detectable systematic motions in the neighbourhood of the apex or antiapex of the first drift will be those of stars belonging to the second drift and *vice versâ*.

In all cases the actual drift motions are obscured by the peculiar motions of individual stars, and this, in combination with the facts that

in certain regions of the sky the influence of one or other drift will predominate, in certain other regions the drifts will give rise to transverse motion in similar directions, while in yet other regions they will be directly opposed, renders the separation of the stars into their component drifts a question of very considerable delicacy.

The difficulties in a large measure disappear if we confine our attention to regions of the sky directly opposite to one another. In such regions the effects of foreshortening due to the inclination of the line of vision to the direction of drift velocity will be exactly similar, and any want of symmetry between such regions must be attributed to other causes.

That there is such a want of symmetry will be clear from these diagrams.

(Diagrams were here shown.)*

The curves shown on these diagrams exhibit the proportion of stars contained within certain limited areas of the sky, the position angles of whose proper motions lie within certain assigned limits. Notice first of all that the majority of these curves exhibit two clearly defined humps or maxima, showing two prevailing directions of the proper motion for each region. These directions are the directions which correspond with the motions of Kapteyn's two drifts. The variation in form of these curves can in part be explained by the different aspects of view of the drifts in different regions, but I wish more especially to direct your attention to a feature which cannot be accounted for in this manner, viz., the contrast between the curves, which correspond with opposite regions; this contrast is more clearly brought out in the third series of diagrams, the ordinates in which represent the differences between those of the first and second, and to account for it we have to suppose that, though the two drifts pervade the whole sky, they are not present in equal proportions in all directions but that first drift stars are relatively more numerous in some regions and second drift stars in others.

I say *relatively* more numerous, as a similar analysis of the actual numbers instead of their proportions seems to indicate that first drift stars are actually distributed fairly symmetrically throughout the sky, and that where they appear more numerous, the phenomenon is to be accounted for merely by a deficiency of stars pertaining to the second drift.

Minor anomalies which it would take too long for me to discuss, al seem in like manner to be associated with the second drift.

These irregularities in distribution in the stars of the second drift, which seem to have no counterpart in those of the first, it should be borne in mind, are the outstanding features over and above the fortuitous

* A more detailed exposition of the diagrams shown has been communicated to the Royal Astronomical Society.

elements which pertain to individual stars. Thus we arrive at the, at first sight paradoxical, conclusion that, while the first drift stars are distributed at random throughout the sky, the very irregularities pertaining to the second drift point to some kind of structural unity in this drift.

Before attempting to explain this further I wish to draw attention to an entirely different method of investigation by which the phenomena I have been discussing may be examined.

I have concerned myself hitherto only with the visible motions of the stars transverse to the line of sight, as derived by the older methods of measurement. The introduction of the spectroscope into astronomical research has opened up vast new fields into which, so far as they relate to the chemical and physical constitution of the sun and stars, it is not my purpose to enter to-night. What I wish rather to emphasise is the value of this instrument as a supplement to the older methods in relation to the geometrical astronomy of position.

In accordance with the principle laid down by Doppler, the wave-length of light received from a source which is either receding from or approaching a receiver will appear to be modified by an amount dependent in a known manner on the velocity of approach or recession. If the receiver takes the form of a spectroscope which permits by any means, direct or indirect, of the measurement of the wave-lengths, and the normal wave-lengths of the lines under examination are independently determined by laboratory investigations, the difference between the observed and the normal wave-lengths will thus afford a means of measuring the velocity of approach or recession of the source of light.

Of the precautions necessary to ensure precision it is not my purpose to speak to-night. The large spectroscope of the Cape Observatory, which we owe to the munificence of the late Mr. Frank McClean, was from the outset constructed with due regard to these precautions, so far as they could be foreseen, for the purpose of determining with the greatest accuracy attainable the radial velocities of stars. The instrument has been already successfully used, and its capabilities have been established in an investigation of the aberration constant of light as depending on the apparent variations in the radial velocities of stars resulting from the earth's orbital motion.

From a relatively short series of observations discussed by my colleague Dr. Halm, this constant has been derived with a precision not inferior to that attained by the best series of older observations, and the capabilities of the method are yet far from exhausted.

At the present time the instrument is being devoted to a series of observations of all such stars as are accessible in the southern skies, whose spectra present sufficiently pronounced features to admit of measurement, primarily with a view to ascertaining what evidence can

be derived from a study of the radial velocities in regard to the systematic structure of the universe.

A year or two must elapse before the present observing programme is completed, but a preliminary discussion of the observations already secured in combination with the published results derived from similar observations in the Northern Hemisphere has revealed the existence of anomalies similar to those found from the study of the transverse motions—anomalies which can only be reconciled with the two-drift hypothesis put forward by Kapteyn, by the further hypothesis that though both drifts pervade the whole sky, they are not similarly distributed throughout it.

At present, through scantiness of material, from a study of the radial velocities, we have been able to do little more than discriminate between the two halves of the sky, which contain respectively the greatest and the least proportion of second drift stars. It is, however, a fact of some significance that the former corresponds very closely with that hemisphere which contains the Milky Way, suggesting the phenomenon that Kapteyn's second drift might be identified with the galaxy. It was with a view to examining this suggestion, in the light of the evidence which could be secured from the transverse motions of the Bradley stars, that the discussions I have sketched to you to-night were undertaken by Dr. Halm.

While they have established almost beyond question the rough features of distribution demanded to reconcile the radial velocity determinations, they further point to an even more detailed correspondence between the distribution of galactic stars and the distribution of stars of the second drift, leaving but little doubt as to the identity of this second drift with the galaxy.

I have pointed out how it is this second drift which exhibits evidence of structural unity. As regards the Milky Way, the mere appearance on any fine night affords evidence of a similar character, and it is on this account that we have been able to identify the Milky Way with the second drift rather than the first.

The significance and origin of this structure is as yet obscure, but the more its details are elucidated and the essential features established the nearer are we to an answer to the question—

What is the Milky Way?

To revert to my original text, I have endeavoured to point out to you the methods of research by which an answer is sought to this and similar questions, and to explain to you the reasons why the highest precision attainable is a *sine quâ non* in the conduct of such research. Thus it is that the study of the large-scale phenomena of the universe resolves itself

frequently into a study of the minute detail of instrumental appliances, on which must be brought to bear all the knowledge that can be derived from other branches of scientific work. The geologist helps us in the selection of stable foundations on which the engineer may erect our large instruments. Chemistry and physics in our photography, our optical and electrical appliances are of daily application, while one of the most valued accessories in almost all methods of precise measurement is the spider's web we derive from zoology.

Astronomy in its turn has done much in the past, and in the future will doubtless do more to assist the development of collateral sciences. Thus the geologist cannot afford to ignore, even if he does not accept as conclusive, the evidence furnished by astronomy as to the nature of the earth's crust. Exact measurements of space and time as conducted in physical laboratories are for the most part conducted by methods first designed to suit the requirements of astronomical precision, while in the sun and stars chemical phenomena, which may be studied with the aid of the spectroscope, are taking place on a scale far surpassing anything that can be produced in the laboratory.

The value of free intercourse between workers in the various branches of science is certainly indisputable, and I wish to close my address by reference to the opportunities which our Society can afford in this respect.

Devotees even of applied, and still more of pure, science in a young country are necessarily few in number and scattered. A large proportion of these will in the early stages of their career have been in close association with one or the other great centres of scientific activity of the world, and to such a feeling of scientific isolation almost amounting to exile, and consequent lack of stimulus, is almost inevitable. Important as are our publications, it is even more through our monthly meetings and the promotion of personal intercourse that the Society can help in its primary duty of—

THE ADVANCEMENT OF NATURAL KNOWLEDGE IN SOUTH AFRICA.

FURTHER OBSERVATIONS ON THE BIOLOGY OF *RORIDULA* L.

By R. Marloth, Ph.D., M.A., F.R.S.S.Af.

(Read May 18, 1910.)

The genus *Roridula*, which consists of two species only, viz., *R. dentata* L. and *R. Gorgonias* Pl., was until recently universally considered to belong to the order Droseraceæ. In his monograph of the order Droseraceæ Diels,* however, explained why in his opinion it could not remain there, and Engler † placed it into the order Ochnaceæ, while Marloth ‡ treated it as a separate family. On the other hand, Wettstein § considers that it is just as much out of place among the Ochnaceæ, and prefers to retain it in Droseraceæ.

The more, however, one studies the structure of the flower and fruit, the less allied does this genus appear to Droseraceæ. In fact its inclusion in this order seems to have been due in the first place, as Diels suggests, more to its apparent insectivorous habits than its floral structure.

The capturing of insects by the plants is so conspicuous, that the shrublets generally show numerous remains, parts as well as entire corpses, of all classes of insects occurring in the neighbourhood—flies and hemiptera, bees and wasps, beetles, moths and butterflies—and as some of these are occasionally of considerable size and weight, sometimes measuring an inch in length, the efficiency of the viscid secretion of the glands is obvious enough.

For some time, however, I have had my doubts as to the nature and function of this secretion, but without experimental proof one could not very well challenge the universal opinion on the subject.

* Diels, L., Das Pflanzenreich, Teil iv., No. 112, p. 51, 1906.
† Engler, A., Syllabus, v. Auflage, p. 164, 1907.
‡ Marloth, R., Das Kapland, p. 360, 1908.
§ von Wettstein, R., Handbuch d. System. Botanik, p. 299, 1908.

In a previous paper * on *Roridula dentata* I described two special features of its biology, viz. :—

1. That it was inhabited by spiders (*Synæma marlothi* Dahl.), which, unimpeded by the viscid secretion, move about freely on the plant and prey on the insects captured by the leaves; and—

2. That an hemipterous insect, viz., *Pameridea roridulæ* Reuter, which was equally immune against the viscid secretion, assisted in the pollination of *Roridula* by piercing the irritable connective of the anthers for the sake of its sugary contents, thereby producing the sudden turning of the anther and the ejection of its pollen.

I am now able to describe some experiments, which demonstrate that the viscid secretion does not possess any digestive properties, and that *Roridula* is therefore not an insectivorous plant.

The Structure of the Glands.—The leaves of both species of *Roridula* bear numerous stalked glands on their margins and on the midrib of the lower sides. While in *R. Gorgonias* the margin of the lanceolate leaf is entire, it is provided with long, narrow teeth in *R. dentata*, the teeth bearing the so-called tentacles (stalked glands) especially near and at their apex. The stalks are of different length, those of the terminal glands being up to 8 mm. long, while those situated on the margin of the leaf between the teeth are generally only 2–3 mm. long. There are no glands on the upper side of the leaf, but on the basal portion of the leaf occur numerous unicellular hairs, on the upper side as well as on the lower one. The structure of the stalk and glands was first described by Darwin,† who recognised, even on the dried specimens, that they showed no signs of inflection, and that, consequently, they are not irritable and movable, resembling in this respect the stalked glands of *Drosophyllum*. He also found that neither the stalks nor the glands possessed any tracheids (called by him spiral vessels) and that there were no sessile glands corresponding to the digestive glands of *Drosophyllum*, but as it was quite possible that the stalked glands might perform the treble duty, viz., secreting a viscid as well as a digestive fluid and absorbing the products of digestion, as is being done by the tentacles of *Drosera*, this difference from *Drosophyllum* did not affect the possibility of the insectivorous nature of the plant. To Darwin's description of the structure of the glands I have only to add that the gland consists of an external layer of large secreting cells (secreting mantle) and an internal cylindrical body, which is merely a continuation of the tissue of the stalk. The cells of the secreting mantle are polyhedral in outline, with thick lateral walls, but without projections and intrusions into the lumen like those of *Drosera*. The contents of the younger glands are of a yellowish green colour like

* Annals of Botany, vol. xvii., No. 65, 1903.

† Darwin, Ch., Insectivorous Plants.

those of the stalks and the tissue of the leaf, but in older glands the head is dark red.

Both kinds, the young and yellowish as well as the old and red glands, are coated with a thin layer of extremely viscid fluid, spreading evenly over the gland and often over the stalk as well like a transparent varnish. This fluid differs from the viscid slime of *Drosera* in the following respects:—

1. It is not miscible with water.

2. It shows no acid reaction, neither when tested direct nor when bits of albumen of egg or meat-fibres are placed on the glands.

3. It readily absorbs iodine from a solution of iodine and iodide of potassium, becoming deep yellow or even brown.

4. It is stained red by alkannin.

These reactions indicate that the fluid is a kind of balsam, and not a slime like that of *Drosera*.

The glands differ from those of *Drosera* as follows:—

1. The membranes of the secreting cells are stained red by alkannin, probably because they are permeated by the viscid fluid. The cell-walls of the glands of *Drosera* are not stained by this reagent.

2. The contact with the white of an egg or fibres of meat does not produce any visible increase of secretion.

3. Neither albumen of egg nor meat-fibres nor diluted juice of meat produce agglomeration of the contents of the cells of the secreting mantle.

4. Weak solutions of ammonium carbonate (1 in 200) do not produce agglomeration nor any other change, except a clearing of the tissue, similar, however, only to that produced by weak glycerin.

These results are, I think, sufficiently conclusive. I may add that I made my first microscopic observations on twigs of the plant brought from the mountains near Tulbagh, the nearest locality known. This means that the twigs were about ten hours old when examined. As this circumstance might have affected the results, I procured some young plants taken out with the soil in which they were growing. The results agreed with my first observations, but in order to be absolutely certain I deferred their publication until I should have had an opportunity of repeating them on plants growing at their natural habitat. This I have been able to do recently, and as the results are the same as those obtained at first in my laboratory, I submit them now to this Society.

I may further mention that plants of *Drosera ramentacea* and *Drosera trinervia*, which were growing in close proximity to the shrublets of *Roridula dentata* on the Tulbagh mountains, showed a very striking appearance when compared with *Roridula*. While the former carried a large drop of fluid at every gland, the glands of *Roridula* showed merely

a faint film of transparent fluid, which became just visible when the leaves were held against the light, although, in order to be quite sure that the absence of drops on the glands was not due to the drying effect of the heat of the day, I had arranged my own visit in such a way that I reached the locality just as the first rays of the rising sun were touching the plants.

The other species of *Roridula*, viz., *R. Gorgonias*, which occurs on the mountains near the river Zondereende and in the Steenbrass river valley, does not differ in the structure of its glands or their behaviour against reagents from *R. dentata*.

The question will be asked, what may be the function of this viscid fluid? My experiments have shown that it does not possess any digestive properties, hence I consider it to be a protection against creeping insects, such as snails, caterpillars, earwigs, &c., and I think that the presence of the capsids (*Pameridea*) supports this view. These capsids live on the juice of the younger shoots and leaves, and during the flowering season on the saccharine contents of the connectives of the anthers, proving that the leaves do not contain any protective substance, at least as far as these insects are concerned.

The capturing of insects is evidently merely accidental, for whether they alight on the shrub or are driven against it by the wind, they become entangled in the viscid fluid and perish, either slowly, as on *R. Gorgonias*, or quickly as on *R. dentata*, being killed in the latter case by the spiders, which inhabit every bush of this species. The genus *Roridula* is therefore to be excluded from the list of insectivorous plants.

With regard to its systematic relationship, I find that it would occupy an anomalous position in Ochnaceæ, and consequently prefer to establish a separate family for *Roridula* and *Biblis*, viz., Roridulaceæ, which should be placed in the neighbourhood of Saxifragaceæ and Pittosporaceæ.

ON THE DEVELOPMENT OF *PIROPLASMA PARVUM* (PROTOZOA) IN THE VARIOUS ORGANS OF CATTLE.

By Dr. R. Gonder.

(Read June 15, 1910.)

Since the investigations of R. Koch on East Coast Fever of cattle in East Africa, the cause of this disease has formed the subject of much discussion.

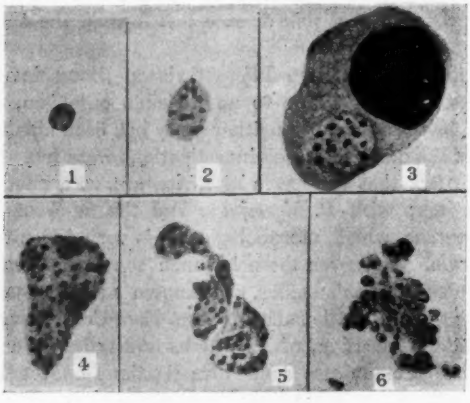
At present there exist two different views. Some investigators hold that East Coast Fever is due to an invisible organism, others declare *P. parvum* to be the cause, but neither party has been able to prove to the satisfaction of the other that their investigations were free of errors. This is due to the fact that the cattle of Africa are, as a rule, infected with various parasites; with *P. bigeminum* and the more or less harmless parasite *P. mutans*, which, morphologically, is very difficult to distinguish from *P. parvum*. Moreover, there is much controversy on the so-called plasma granules or Koch's bodies, also known as blue bodies, which are found in the organs of cattle suffering from East Coast Fever.

In this short publication, which will be succeeded by a more detailed one, I wish to communicate some investigations on the blue bodies of Koch which will throw some light on their nature. For the present I shall leave out details, neither can I enter into the literature on the subject, which will have to be considered in the more exhaustive report.

Experiments were carried out since March of this year in the Transvaal Veterinary Bacteriological Laboratory. The material used consisted in cattle whose origin we know and in ticks with whose history we were fully acquainted; accordingly double infections could be excluded from the very start. The ticks placed on control cattle imported direct from England proved that they were exclusively infected with East Coast Fever. In addition to this, Dr. Theiler gave me permission to utilise the cattle used in various experiments on East Coast Fever which had been infected experimentally through the implantation and inoculation of different organs. For my zoological studies, therefore, a considerable amount of material was available.

Before discussing the question of Koch's bodies, I wish to make some remarks on *P. parvum*. Last year Ollwig, at the Congress of Microbiologists in Berlin, stated that *P. parvum* and *P. mutans* were identical. My experiments leave no doubt that *P. parvum* and *mutans* are two different organisms, which view has been held for a number of years by different authors. Blood containing *P. parvum* in extraordinarily large numbers was injected subcutaneously and into the organs of various animals, and in no instance was an infection transmitted. On the contrary, it was an easy matter to transmit *P. mutans* to a healthy beast. An emulsion of 1 c.c. red corpuscles in 10 c.c. saline solution was sufficient to do so. As a further proof, it may be stated that *Rhipicephalus appendiculatus* in the Transvaal transmit *P. mutans* only in exceptional cases.

P. parvum *and* P. mutans *are therefore, with regard to their pathogenic*



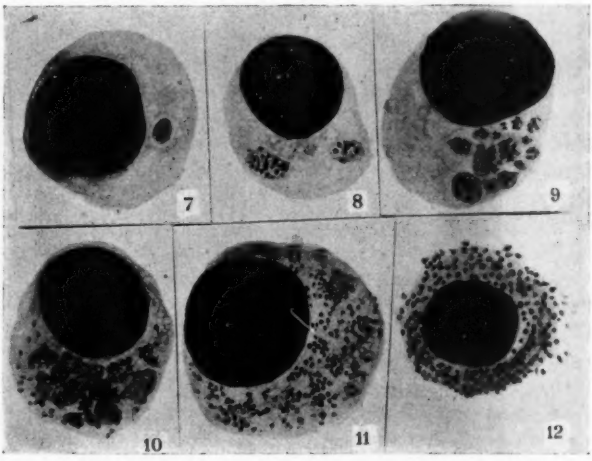
effect, two different parasites which also show differences in their cycle of development.

Together with the daily blood examinations, systematic punctures of glands and spleen were made. On comparing preparations from cattle suffering from East Coast Fever with those infected with *P. mutans* no doubts can be left about the cause of East Coast Fever. Shortly before the parasites appear in the blood one will notice segmenting forms of Koch's bodies which throw off a great number of parasites. For this investigation the large shoulder glands are the most suitable. Neither an infection with *P. bigeminum* nor one with *P. mutans*, *P. equi*, or *P. canis* shows similar evolution forms, whereby it is proved that Koch's bodies represent a stage in the development of *P. parvum*, as already Koch him-

self had surmised. Accordingly the view of Martin Mayer, that the so-called Koch's granules are not specific for East Coast Fever, falls to the ground.

The blue bodies represent, indeed, a certain stage in the cycle of P. parvum *which corresponds to the shizogony in the cycle of the malarial and other parasites.*

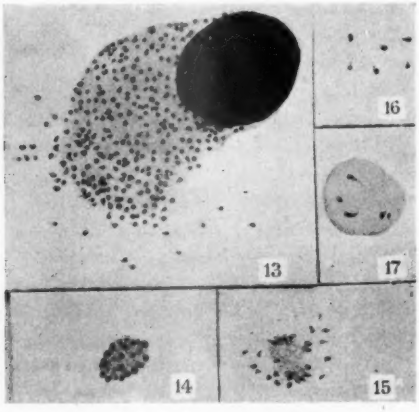
These bodies appear both intracellularly and extracellularly, more particularly in the lymphocytes. Quite exceptionally polynuclear leucocytes are found to be infected. The development takes place more or less in the following manner. In the blue body (Agamont) the nucleus is first formed; this grows and becomes richer in chromatin and plasma; subsequently it divides successively into a great number of smaller nuclei



similarly to what occurs in the cycle of hæmoproteus which takes place in the organs of the pigeon and padda. The cells thus formed break up into as many subdivisions as there are nuclei (Figs. 1–6). One encounters but rarely a second one, to which I will refer hereafter. The explanation of this fact may be that this shizogonous stage, which I call, with Hartmann, Agamogony, repeats itself. Accordingly agametes, resulting from the agamogonous stage, would grow into agamonts. I have, however, not been able to completely follow up the further development of these later forms.

The second mode of multiplication ends with the segmentation into a great number of small parasites, undoubtedly resulting from the agamo-

gonous multiplication (Figs. 7–13). The young parasites enter into the red corpuscles, and represent now the forms known as *P. parvum*. Thus we have in the organs, particularly in the lymphatic glands and the spleen, two different phases, which morphologically are not difficult to distinguish from each other. The nuclei of the one phase (agamogonous) when young show a loose structure, and are irregularly shaped. The nuclei of the second phase, that is, of the second generation or gamogonous, take the nuclear stains more deeply; they undergo reductions, and accordingly appear smaller. Before the segmentation of the nuclei has taken place they are oval-shaped. One is struck by the fact that the extracellular segmenting forms of the gamogonous generation produce parasites in far smaller numbers (Figs. 14–15) than those found in the cells themselves



(Figs. 12–13). I have not been able to give an explanation of this observation. In the blood no multiplication has as yet been seen, but my studies on these parasites are not yet concluded. Plasma granules were found in the blood, but this fact by no means necessitates a change of the above technology. It may also be possible that two agamogonous stages have to be distinguished, and the parasites which develop in the red corpuscles would have to be considered as the gamogenous generation. I am, however, of the opinion that the two stages in the cycle which I have called provisionally agamogony and gamogony, and which finally lead to the formation of the forms seen in the blood, succeed each other within the cell. Accordingly it is clear that the number of parasites increase as the disease develops. The forms which result from the segmentation of the last generation differ morphologically in no way from the parasites

seen in the blood at the commencement of an infection. They possess, in proportion to the whole parasite, a large nucleus, which contains a distinctive Karyosome. In using Giemsa's stain one can see differences due to the staining in the plasma of the bodies belonging to the agamogonous stage as well as of the gamogonous one. There are dark blue forms along with light blue ones containing larger alveoli. It is possible that from the very start we have to deal with a sexual differentiation. The above nuclear phenomenon can easily be studied in preparations stained according to the dry and moist methods of Giemsa, as well as in those stained with hæmotoxylin. Microscopic examination of the various organs, particularly of the spleen, does not always allow of definite conclusions. These organs represent a filter, which retains the broken-down parasites usually encountered in all protozoal diseases. When using the vital method I was never able to recognise the blue bodies, so that it is impossible for me to believe that these represent an assimulation product of the nuclei. The presence of Koch's bodies in the kidneys is of secondary importance. In East Coast Fever experimentally produced, either through the implantation of organs or in cases brought on by ticks, which finish rapidly with death, the formation of infarcts in the kidneys may not take place at all. My drawings of, and the communication referring to, Koch's granules, concern fresh material obtained with a syringe from the lymphatic glands and the spleen. In cases of East Coast Fever where fever is present without parasites being present in the blood, the diagnosis can be made by examining juice from the spleen and lymphatic glands. If in the juice obtained from the puncture of the lymphatic glands or the spleen are seen Koch's bodies containing only larger nuclei of a loose structure, and no forms of the second or gamogonous generation, it is possible that this latter does not take place at all, and no parasites are then found in the blood. Whether ticks which have been sucking the blood of such animals transmit the disease will be shown by later experiments.

It remains to explain the fact that the blood of animals suffering from East Coast Fever injected into healthy animals does not produce the disease. It is possible that the blood contains forms which can only develop in the tick, and which, injected into the animal, die. In the transplantation of organs undertaken by Theiler and Meyer, Koch's granules are directly transmitted. These represent, under natural conditions, the stages which are formed only after the tick has transmitted the disease. The infection of the various glands in the body of an animal takes place through the blood current, and accordingly it becomes feasible to expect that the inoculation of blood also ought to produce the disease. A suitable occasion would probably arise when the plasma granules are found in the blood. Experiments to elucidate this will be carried out as

soon as opportunity occurs. In an animal which was infected by the transplantation of organs I found Koch's granules in the blood. Dr. Meyer showed me blood-smears sent in from the practice in which a great number of mononuclear leucocytes contained the plasma bodies.

Concerning the place of the East Coast Fever parasite in protozology, the proposition of Bettencourt and others to separate it from the piroplasms and to substitute a new name (*Theileria parva*) is justified.

DESCRIPTION OF THE FIGURES.

FIG.
1–6. Agamogonous generation.
3. Intracellular form.
7–13. Intracellular gamogonous forms.
12–13. Gamogonous forms in segmentation.
14–15. Free gamogonous forms.
15. Free gamogonous form in segmentation.
16. Free parasites.
17. Parasites in the blood corpuscle.

"ANAPLASMA MARGINALE."

A NEW GENUS AND SPECIES OF THE PROTOZOA.

By A. Theiler, M.D., F.R.S.S.Af.

(Read June 15, 1910.)

In the Annual Report of the United States Department of Agriculture for the years 1891 and 1892 Smith and Kilborne published their investigations into the cause of Texas Fever, which was found to be due to the presence of an endoglobular parasite, and to which they gave, at that time, the name of *Pirosoma bigeminum*. They described two forms of the disease, the acute and the mild one, which latter they also called the autumnal form. The differentiation of these two diseases was based on the aspect the parasites took in the red corpuscles, which, although differing in shape and size, were considered to belong to two phases in the cycle of development. Accordingly they distinguished the pear-shaped parasite now called *Piroplasma bigeminum*, and which they identified with the acute form of Texas Fever, from the second form, the peripheral coccus-like body of the mild or autumnal form of Texas Fever. Smith and Kilborne based on these observations the possible life cycle of *P. bigeminum*, of which they described three stages :—

(1) The (hypothetical) swarming stage, the form of which, however, as they state, could not be traced.

(2) The stage of the peripheral coccus-like bodies, which bodies they thought would develop into

(3) The spindle or pear-shaped stage

Smith and Kilborne already noticed that their third stage is the one which is usually met with in acute Texas Fever. They had therefore to explain the absence of the coccus-like bodies in the acute stage, and their explanation was that the presence of the coccus-like bodies may be so ephemeral that they escape observation. Under the influence of the temperature of the autumn the second stage would remain as such, and not develop into the third one. In this second stage they would cause the mild disease.

To understand this explanation it may be stated here that Smith and Kilborne undertook their experiments usually in July, August, and September, and it was during September, October, and November that they met with the disease due to the coccus-like bodies. In subsequent observations made in South America by Knuth, the same coccus-like bodies were seen again. This author did not support the view of Smith and Kilborne about the three different stages, yet nevertheless he considered the coccus-like bodies to belong to the life cycle of *P. bigeminum.* On the other hand, Djunkowsky and Luhs, who were studying the piroplasms in the Transcauscasus, came across the same parasite; they had noticed the presence of *P. bigeminum* in that country, but they did not identify the coccus-like body with this disease, but with another one, which they called tropical piroplasmosis, and which is due to a small piroplasm called *P. anulatum,* very likely identical with our *P. parvum.*

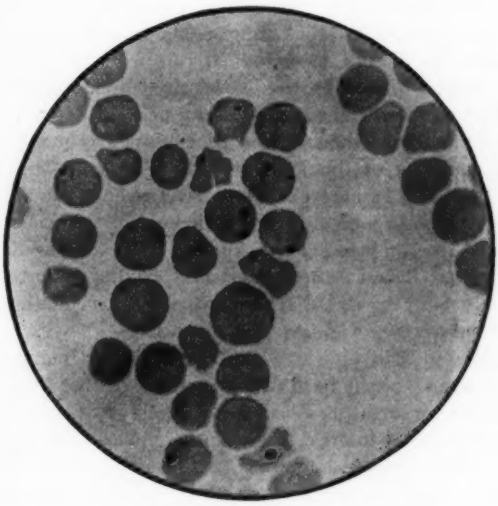
In South Africa I have seen these parasites for a number of years. The American literature not being available to me at the beginning of my investigations, I described them as marginal points in my various reports. The observations which I made led me to think that these marginal points had nothing to do with *P. bigeminum,* but that they represented an independent parasite genus of their own, and that they were the cause of a definite disease, which had to be separated from Redwater. I was, however, until recently, unable to give this proof in such a way as would remove all doubts.

Some years ago I sent ticks (*Boophilus decoloratus*) to England which were infected with *P. bigeminum.* They produced the disease in London when placed on an ox, and this ox formed the starting-point of many investigations and inoculation experiments undertaken in England. As a result of such investigations Nuttall described the cycle of development of *P. bigeminum* in the blood, and, according to this author, it is a simple division, as in the case of *P. canis.* He does not mention any forms corresponding to the coccus-like or marginal points mentioned before.

In Germany the disease Hæmoglobinuria of cattle was also investigated during the last few years; it was found to be due to a piroplasm which, owing to some slight difference, is considered to be a species of its own, and is called *P. bovis,* but it is very closely allied to *P. bigeminum.* No parasites resembling the peripheral coccus-like bodies were noticed in the life cycle of this parasite.

Stockman and myself have carried out, for a number of years, experiments to immunise English cattle. The cattle were inoculated in England against South African Redwater with the strain of Redwater forwarded by means of the already mentioned ticks; after the inoculation the animals were sent to the Transvaal to be exposed here. In the first lot of cattle exposed I noticed the appearance of marginal points in the

blood of two animals which succumbed to the disease. A second lot of ten heifers, which were all immunised in the same way in London, were not exposed to natural infection after their arrival, but inoculated a second time in the Transvaal with blood containing *P. bigeminum.* The result was that this inoculation did not break the immunity against Redwater. After a certain period, varying in length from twenty-seven to thirty-two days, a typical fever reaction commenced, which was initiated and accompanied by the presence of marginal points. Of ten animals injected five died. It was evident that *P. bigeminum* was not responsible for this disease. With the inoculation of the blood two different parasites had been injected—*P. bigeminum*, against which the animals were immune,



ANAPLASMA MARGINALE.

and another one, the marginal points, which caused the disease. If this conclusion was right it had to be expected that it would be possible to separate these two parasites, at least to isolate the one with the shorter incubation time. It was indeed possible to do so with *P. bigeminum*, whose incubation period is the shorter one. A pure infection resulted after injections of blood, taken at the beginning of the acute attack of Redwater, into a susceptible beast. When this animal, at a later period, was infected with marginal points, it promptly reacted to this infection.

The reverse experiment was not so easy, because wherever we had an infection with marginal points it was complicated with *P. bigeminum*, so

that the inoculation of such blood would constantly cause Redwater in the first instance. An observation I had made showed that animals imported from Aliwal North, although promptly reacting to Redwater, did not do so to the injection of blood containing marginal points. I concluded, therefore, that these animals are immune against this latter parasite. It had to be expected that when blood of such animals was injected into susceptible animals, only marginal points would appear. This has been done in several instances, and in every one, after a typical long incubation time, marginal points alone appeared. After recovery the animals were injected with *P. bigeminum* of a pure infection; the result was that they showed this parasite after the usual period of incubation. Thus the independence of marginal points to the cycle of *P. bigeminum* was demonstrated in the reverse order. Accordingly, no doubt can any longer be left that these peripheral bodies represent a genus of their own which produces a specific disease in cattle.

I have proposed to give the name *Anaplasma marginale* to this parasite. This anaplasm is transmitted by ticks, and it is a noteworthy fact that the incubation time by tick transmission is much longer than that after inoculation of the animals with blood; in the experiments carried out by me it varied from fifty-five to seventy-five days. Accordingly we understand the results of experiments of the Americans, which were started in the summer. They exposed cattle to tick infection; they noticed the appearance of *P. bigeminum* first, having a shorter incubation time, and only later in the year, after the long incubation time, they noticed the appearance of *Anaplasma marginale.*

It has already been indicated that blood of an immune animal is infective; such an animal forms the reservoir of the virus. This is a peculiarity of the piroplasma diseases, to which group anaplasmosis also belongs. It may be of interest to state my opinion that anaplasmosis is probably the disease which the farmer has hitherto called Gall Sickness. Up to the present time we know of three different parasites in South Africa which are found in the blood of immune cattle—*P. bigeminum*, *P. mutans*, and *Spirochæta theileri*—and to these will now be added *Anaplasma marginale;* they can all be transmitted by the inoculation of blood and by ticks.

A FURTHER NOTE ON THE DIURNAL VARIATION OF LEVEL AT KIMBERLEY.

By J. R. Sutton, ScD., F.R.S.S.Af.

(Read July 20, 1910.)

I have made a number of experiments during the past few months with the object of determining whether the diurnal oscillation of level is by any chance wholly or in part of photo-electrical origin; since, for reasons already stated, neither the distortion of the crust by heat and cold, nor the movements of subsoil water, nor the variation of load set up by the diurnal march of barometric pressure, seem to be competent to produce more than a small portion of the oscillation.* The results obtained so far are conflicting; while some have appeared to support the idea, others do not. The investigation, which is being continued as occasion offers, will be described later on, provided it yields anything definite and succeeds in reconciling the discrepancies.

My meteorological observations are not in disagreement with some kind of photo-electric theory of the diurnal oscillation of level. Seeing, nevertheless, that the earth's surface at Kimberley is scarcely ever at rest —the level being depressed north, south, east, and west almost unceasingly —no great amount of success is to be anticipated in disentangling the elements that really matter from those that do not. A heavy shower of rain, for example, will set up very large disturbances of level lasting many days, and interfering considerably with the diurnal oscillation. The passage of a barometric depression also has its own disturbing influence, which may be added on occasion to that of the rain. The following numbers show the daily averages of the hourly values of the deviation, to the west of the datum line, of the stylus of the horizontal pendulum,

* "Preliminary Note on the Diurnal Variation of Level at Kimberley," Trans. R.S.S.A., July, 1909.

following a heavy rain over Kimberley (5 inches in 12 hours) on March 20, 1910:—

TABLE 1.

DAILY AVERAGE DEVIATION OF THE HORIZONTAL PENDULUM TO THE WEST.

March 20	.....	40·4 mm.
21	.....	37·7
22	.....	26·3
23	.....	18·8
24	.....	14·5
25	.....	10·3

This indicates a great depression of the east end of the level, due no doubt to the fact that a great deal of the storm water both ran directly off the ridge on which Kimberley is built as well as percolated downwards to the lower land eastwards, thus increasing the load and depressing the level on the side where it settled. Later on there was a gradual recovery. The pendulum, being reset to somewhere near its first value, recorded the following daily average readings:—

TABLE 2.

DAILY AVERAGE DEVIATION OF THE HORIZONTAL PENDULUM TO THE WEST.

March 26.....43·2 mm.	April 3.....44·1 mm.	April 11.....55·8 mm.
27.....43·1	4.....44·7	12.....56·1
28.....41·2	5.....44·4	13.....56·3
29.....40·8	6.....44·6	14.....56·4
30.....41·1	7.....47·3	15.....57·2
31.....41·2	8.....48·4	16.....58·6
April 1.....42·8	9.....49·8	17.....60·1
2.....43·7	10.....51·5	18.....60·4

It appears, therefore, that the movement of the pendulum to the east lasted ten days, the recovery to the west taking at least twice as long.

To show the effect of the passage of a barometric depression upon the level, forty-four fairly typical and well-defined depressions were selected, and the average barometric pressure on five successive days—the third of

which is the day of least pressure—have been compared with the daily ranges of the pendulum from east to west for the same days. The following are the results :—

TABLE 3.

SHOWING THE EFFECT OF BAROMETRIC PRESSURE UPON THE DIURNAL RANGE OF THE HORIZONTAL PENDULUM.

	Barometer. Mean.	H.P. Range. Mean.
Day 1	26·129 inches	5·9 mm
2	26·058	5·8
3	25·987	3·9
4	26·075	4·4
5	26·133	6·9

The mean daily range of the pendulum being 5·5 mm., it appears that when the barometer is lowest during the passage of a depression the range is 71 per cent. of the mean, whereas in the wake of the depression the range rises to 125 per cent.* The state of the sky is conceivably responsible for a large part of this difference.†

Table 4 shows the mean results of a comparison between various meteorological elements and the range of the horizontal pendulum. It is got (1) by arranging the daily duration of sunshine in order of magnitude each month, together with the corresponding values of earth temperature range at a depth of 1 inch; earth temperature maximum; maximum in the sun (black bulb *in vacuo*); range of barometric pressure; and range of the horizontal pendulum from east to west. (2) By dividing the monthly sets thus arranged into threes, each including as nearly as possible the same number of days, one set including all days with little sunshine, another with a medium amount, and the third set with a great deal. (3) By taking the annual averages of each of the three sets.

* This is the only relationship between the height of the barometer and the movement of the pendulum that I have been able to detect in anything like a definite way. That the pendulum at Kimberley does not deviate in any marked fashion from the centre of an approaching depression may be due to the fact that our storms usually travel from SW. to NE., and therefore cannot affect the gradient at right angles to the meridian to the same extent as they would if they travelled from W. to E. Probably, however, the views set forth by Dr. Klotz (Report of the Chief Astronomer for 1907–8, Ottawa, 1910) will make it necessary to reconsider the whole question of the relation between the variations of atmospheric pressure and level.

† The amount of cloud increases gradually as a depression approaches, and decreases rapidly as the depression passes away.

TABLE 4.

METEOROLOGICAL ELEMENTS COMPARED WITH THE CORRESPONDING RANGES OF THE HORIZONTAL PENDULUM.

	Cloudy Days.	Medium Days.	Clear Days.
Mean duration of sunshine *	387	634	699 minutes
Range of earth temperature	47	58	61 degrees
Maximum of earth temperature ...	98	106	108 ,,
Maximum in the sun	138	139	138 ,,
Range of pressure	26·087	26·098	26·088 inches
Range of pendulum	4·7	5·9	6·3 mm.
Number of days	266	293	288 days

It appears from this that the range of the pendulum increases as the daily duration of sunshine increases. The same range is evidently independent of the variation of the diurnal range of pressure, and also of the direct heating power of the sun so far as the black bulb *in vacuo* is competent to measure it. That the range of earth temperature should depend upon the duration of sunshine is no more than would be expected, seeing that under a clear sky nocturnal cooling goes on very rapidly. It is not easy to see, however, why the maximum temperature just under the surface of the ground should be, on the whole, highest under clear skies. According to the indications of the black bulb, the greatest heating effect accompanies a sky about one-half clouded, and a very high temperature on the black bulb is as a rule accompanied by a high temperature of the surface soil. But of course the black bulb attains a maximum in a very few minutes, whereas the ground takes time to warm up, as shown by the fact that the mean maximum for the day at a depth of 1 inch occurs somewhere near $1\frac{3}{4}$ h. p.m.

Table 5 gives the results of a comparison between the range of temperature of the surface soil, the duration of sunshine, and the mean daily range of the horizontal pendulum, arranged in sets according to the magnitude of the range of earth temperature.

TABLE 5.

RANGE OF EARTH TEMPERATURE AND DURATION OF SUNSHINE COMPARED WITH THE CORRESPONDING RANGE OF THE HORIZONTAL PENDULUM.

	Cloudy Days.	Medium Days.	Clear Days.
Range of earth temperature.....	43	57	66 degrees
Mean duration of sunshine	464	615	657 minutes
Range of pendulum	4·7	5·9	6·4 mm.

* Photographic record.

This arrangement gives the same values for the average daily swing of the pendulum, but it shows a smaller range of earth temperature on cloudy days, and a greater range on clear days than the arrangement of Table 4. On the other hand, it shows more sunshine on the cloudy days and less on the clear days than that Table does.

It seems to follow from this relation between the diurnal oscillation of level (as shown by the horizontal pendulum), the duration of sunshine, and the range of temperature of the surface soil, that if the oscillation is of photo-electric origin then it must depend upon the energy of waves of fairly long wave-length, *i.e.*, upon waves that are effective as heat rays rather than upon the more strictly actinic rays.

VERNEUK PAN.

By A. W. Rogers, Sc.D., F.R.S.S.Af.

(Read July 20, 1910.)

Verneuk Pan, which gets its name from the prevalence of mirage, is roughly 17 miles long and 6 wide; the longer axis lies W.S.W.–E.N.E.

Though both the Olifant's Vlei River, which drains a large area in Carnarvon, and the smaller Hartog's Kloof River cross the extreme east end of the pan, and probably supply the greater part of the water which occasionally floods its surface, the pan itself is not merely an expansion of their valleys, which are extremely ill-defined in this neighbourhood. The pan is drained across a narrow dyke of dolerite, which just projects through the sandy mud at its E.N.E. end. Several short valleys, the longest of which heads in the dolerite escarpment of Jan Louw's Kolk, 15 miles south of the pan, may at times bring water to it, but these valleys are themselves chains of bare pan surfaces which probably retain all the rain-water except during the heaviest rains.

The outline of Verneuk Pan cannot be accurately defined; on the east, north and south-east there is an extremely gradual ascent to the veld outside the pan, so that one can walk 2 or 3 miles across the boundary without being able to decide where one leaves the pan itself. Towards Zwart Kop,* a dolerite hill south of the middle of the pan, the limit is more clearly defined, as the ground rises more rapidly in that direction than elsewhere, though even there the strip of doubtful ground is some 500 yards wide. The west side of the pan I only saw from a distance of about 5 miles; shales and a dolerite sheet form low hills towards which the ground rises rather rapidly.

The pan floor is either a yellowish-grey, sandy mud, or crumbly dark shale and fibrous limestone; it lies entirely within the middle portion of the Upper Dwyka shales, which have a very low southerly dip. The

* It may be noted that the village of Zwart Kop, which is marked on most maps, does not exist in fact. In 1909 there was one hut, occupied by a Damara, on its site.

outcrops make slight rises on the floor, probably never more than 6 inches high.

The most remarkable fact about the floor, after its flatness, is the thinness of the layer of sandy mud. The total area of bare shale and limestone surface within the pan must be considerable, and over a still wider area the joints traversing the rocks below are clearly outlined by damp streaks or lines of salt left behind on the evaporation of the water along the joints. This indicates that the mud covering the shale is thin. At several places I scratched away the mud and exposed shale at a depth less than 4 inches. The mud contains small crystals of gypsum. In an abandoned well or prospecting pit in the middle of the eastern part of the pan there is exposed a section showing 3 inches of sandy mud lying on a quarter of an inch of gypsum, directly below which are dark shales with occasional thin layers of fibrous limestone.

Though there is much mud where the Olifant's Vlei River comes into the pan, and at the time of my visit in September, 1909, this mud was still so soft that I could not cross it, there seems to be no buried channel in the pan itself, and the silted-up bed of the Olifant's Vlei River cannot be much deeper than the level of the dolerite lip, over which part of its waters are discharged.

There can be no doubt that the pan is essentially a flat surface cut in the shales. The presence of the hard dolerite lip checks the downward cutting of water in the shales behind it. The shales, though some layers are hard, are fragile rocks which break up into small fragments on exposure; the limestones are more resistant rocks, but owing to their fibrous structure they break up much more quickly than the calcareous layers and nodules in the Dwyka tillite.

There was no vegetation on the mud of the pan in September, 1909, but the shale patches bore clumps of a small-leaved, bright green, succulent plant, especially towards the outer part of the pan. Though there were no visible deposits of salt beyond occasional films a few feet wide, and the lines marking joints in the underlying shales, the sandy mud of the floor probably contains a fair amount of common salt in addition to the small gypsum crystals scattered through it.

The Upper Dwyka shales yield brackish water, but in September of last year water in the long kolk in the course of the ill-defined valley leading from the east side of Bushman's Berg was still fresh enough to drink, though that in the pools along the Olifant's Vlei River was useless to man and donkeys. Water flowing westwards from the latter river over Verneuk Pan must bring salt with it, some of which remains behind on each occasion.

The explanation of the cutting of such a wide tract of flat country as Verneuk Pan is not easy to find, but a consideration of the behaviour of

the rivers in the district, where they flow from soft, nearly horizontally bedded rocks on to the hard granite* of Kenhardt affords part of the explanation. The valleys are extremely wide and usually without a definite river-bed as long as they lie on the Upper Dwyka shales; but when they reach the tillite below, a bed sometimes appears, and the sides of the valley close in; when they reach the granite there is always a well-defined narrow bed with steep banks, and the valley sides become cliffs in places, as, for instance, at Modder Gat on the Hartebeest River. Measuring the fall on the contoured 4-inch-to-the-mile maps made by the Topographical branch of the War Office, the grade of the rivers increases from about 1 foot to the mile on the Dwyka formation to 8 feet to the mile on the granite. The granite forms a hard bar, and the rivers cannot widen their valleys in the granite so long as the Orange River cuts down its bed at a faster rate than they can keep pace with, which it does because it drains a large area with a rainfall greater than that of the catchments of the Hartebeest and its tributaries.

Above the granite barrier, which is always moving up-stream and, on the average, falling in level, the rivers have cut their beds to the gentlest possible grade for a considerable distance, and their present work is, over that distance, confined to cutting plains laterally in the soft rocks behind the barrier and distributing thin sheets of fine silt over these plains.

On the small streams tributary to the Zak and Olifant's Vlei Rivers, in the lower parts of their courses, a similar process goes on behind each dyke sheet of dolerite or other hard rock which lies athwart their paths, but in these cases the soil becomes very brack, probably from lack of sufficient drainage when the valleys have passed a certain slope, and vegetation will no longer thrive on the mud flats in these valleys as it does on the flats of the Zak and Olifant's Vlei Rivers, which are periodically thoroughly washed by heavy floods. When there is a dearth of vegetation the wind attacks the mud more readily than before, and lays bare the underlying shales in places. The wind perhaps does a certain amount of actual rock-cutting with the help of the sand grains picked up from the floor of the pan, but a careful inspection of many outcrops and loose fragments on Verneuk Pan failed to reveal any noticeably sand-cut or polished surfaces, probably because the shales and thin fibrous limestones break up too rapidly under the influence of the weather to allow the retention of the evidence. In any case the wind removes material from the outcrops, as well as from the dry mud of the pan, as soon as the fragments are small enough.

* For the purpose of this description the ancient rocks of Kenhardt are called granites throughout, but they are in fact not often true granites, for they consist largely of gneiss and various schists of sedimentary or volcanic origin. Their important character here is their comparatively great hardness.

Sand dunes are prominent features in the country south of Verneuk Pan and within 5 miles of it, and they certainly derive part of their material from it. How much of the sand is obtained in this way would be a difficult question to answer, even after a detailed investigation, for the Karroo strata, which furnish the sediments in the pan, are themselves made of the minerals which might possibly be contributed to the dunes by the ancient rocks of Kenhardt.

The conclusion to which a brief study of Verneuk Pan and the surrounding country leads, then, is that great flat surfaces practically devoid of vegetation may be primarily due in this region to the extremely low grade reached by streams behind bars of hard rock, then to the consequent unfavourable conditions for plant-growth owing to the increasing brackness of the soil, and finally to the scope thus given to the wind to remove dust and sand from the bare ground.

GRAVITY IN SOUTH AFRICA.

By R. A. Lehfeldt, D.Sc., F.R.S.S.Af.

(Read March 16, 1910.)

Shortly after arriving in Johannesburg, the author made a rough determination of "g," as that quantity was at the time unknown. The result, 9·786 metres/sec.^{2}, was published in the Philosophical Magazine, Nov., 1906. As the South African tableland is one of the only two really large tablelands in the world—the other being Tibet—a certain geophysical interest attaches to gravity measurements there, and it was hoped that they might be continued with proper apparatus. The author applied to the hydrographical department of the Austro-Hungarian Government, which has long shown itself interested in the matter, and the Director very courteously and promptly lent the author three pendulums of the well-known Sterneck pattern, such as had been used for gravity measurements at coast stations by officers of the Austrian navy, together with subsidiary apparatus. The author desires to convey his thanks to the Austro-Hungarian Government for this loan, and to others for incidental assistance rendered during the observations—the South African railways for transport facilities, the Post Office for the use of telephone lines, and especially to Mr. R. T. A. Innes, Director of the Transvaal Observatory; Mr. Hough, of the Royal Observatory, Cape of Good Hope; and Capt. Lacerda, of the Observatory, Lourenço Marques.

Although the method of measurement is well known, it has not always been easy to find satisfactory conditions for observation in a new country. This, coupled with the limitations of time at the disposal of the author—vacations only being available—has resulted in but a small number of measurements being carried out. These, however, throw some light on the problem of the tableland, and it is therefore thought worth while to publish them without waiting for more.

STATIONS.

Johannesburg, South African School of Mines and Technology
(formerly Transvaal Technical Institute).

Latitude	26° 11′ 47″ S.
Longitude	28° 2′ 32″ E.
Altitude	1,749 metres.

The measurements were carried out in the basement of the old Telephone Tower, the pendulum (on the "pfeiler-stativ") resting on a massive concrete block: temperature was satisfactorily steady. The times were observed sometimes by means of signals transmitted from the sidereal clock of the Observatory over the telephone lines to a relay and thence by a separate battery to the coincidence apparatus, and sometimes by the Carroll chronometer.* Although in the centre of the town, the building was free from shaking. The land slopes very slightly upwards to the north, near the building, but it may be taken as practically flat for half a kilometre in every direction. Further away the land slopes downward both northwards and southwards, Johannesburg being placed on the ridge of the Witwatersrand hills. The underlying strata are shales and quartzites, to a depth of at least 1,500 metres below the surface: density probably about 2·7.

Johannesburg Observatory.

Latitude	26° 10′ 55″ S.
Longitude	28° 4′ 30″ E.
Altitude	1,805 metres.

The pendulum was placed on the ledge of the east window of the basement, being screened from the sun by a wooden shutter, the "pfeiler-stativ" used, with the usual glass cover. The times were observed by signals from the mean-time (Riefler) clock of the Observatory; this was compared chronographically with the sidereal. Temperature steady, and support solid. The Observatory is situated at the highest point of the town, on a ridge of quartzite, the land falling away sharply both to north and south.

Vereeniging (Post Office).

Latitude	26° 40½′ S.
Longitude	27° 55½′ E.
Altitude	1,436 metres.

The pendulum was placed on the "pfeiler-stativ" on the ledge of a window, which was too narrow to allow the usual cover to be used: it

* The best set out of several is alone quoted below. More weight is to be given to the measurements at Johannesburg Observatory.

was screened from draughts by paper. The temperature was moderately constant. The coincidence apparatus was worked by the Carroll chronometer (with electric contacts), and the latter was checked by means of telephonic signals from the Johannesburg Observatory. There was, however, some difficulty in getting these signals, which had to traverse about 50 miles, owing to imperfections in the line. Only pendulum **62** was used.

The surface and the underlying strata are *very* flat; surface rocks, clay and shales.

Cape of Good Hope (Royal Observatory).

Latitude	33° 56′ 3″ S.
Longitude	16° 8′ 26″ E.
Altitude	16 metres.

The measurements were made in the space under the floor of the Maclean telescope, the pendulum resting (on the "pfeiler-stativ") on a massive buttress of the wall. Stability and temperature conditions very good. The coincidence apparatus could not be worked by the clock (a Riefler) direct, so the Carroll chronometer was used, and compared by ear with a sounder worked by the Riefler. The single coincidences could not be obtained in this way nearer than $\frac{1}{10}$ second. The rate of the chronometer varied a good deal during the day of observation, and an attempt was made to draw a curve of the variation and correct the observed periods by that (Fig. p. 125); but the results were uncertain.

The Observatory is situated on a slight eminence in an otherwise flat, sandy country. The mass of Table Mountain (about 1,000 metres high) lies from 1 to 2 kilometres away to the SW., and stretches to a considerable distance, embracing about a quarter of the horizon.

Lourenço Marques Observatory.

Latitude	26° 2′ 31″ S.
Longitude	32° 19′ 48″ E.
Altitude	55 metres.

A large brick pillar was built in the basement of the clock-house, and the pendulum erected on it, and provided with the usual glass cover. The oscillations were in the EW. direction, the telescope being to the south. The temperature was very constant; the pillar was tested for stability and appeared quite satisfactory. The coincidence apparatus was worked direct by the sidereal clock (Strasser and Rohde).

The Observatory is placed on a small, sandy plateau, extending for 300 or 400 metres to the east (towards the sea), and more than a kilometre in all other directions. A map of the coast was examined

with a view to estimating the correction for variations of altitude of land and depth of sea; it was concluded that the attraction could safely be taken as that of an indefinite plateau of height 55 m. and density about 2.

Criticism of Method.

It is unnecessary to describe the method of using the Sterneck apparatus, which has already been described more than once; but some remarks on it have occurred to the writer during the course of the work.

Three pendulums—numbered 23, 44, and 62—were provided, and two stands, one for use on a pillar, the other against a wall; of the two stands the former has been used, for the most part. The corrections to be applied are for—

(*a*) Rate of clock.
(*b*) Amplitude.
(*c*) Temperature.
(*d*) Density of air.
(*e*) Oscillation of support.

(*a*) In order to render this as certain as possible, it is desirable to extend the observations as nearly as possible over twenty-four hours, so as to make use of the average rate of the clock determined by observations of the stars. In the case of a good observatory clock it is probable that no sensible diurnal variation of the rate occurs; though this is a point not quite satisfactorily settled; whilst the variation in rate of a good clock from one day to another is hardly sufficient to affect the value of "*g*" by more than one in a million. Chronometers, however, usually show a diurnal variation—an effect that has been but little studied; and when moved about from place to place undoubtedly suffer irregular changes of rate; hence it is all the more important in this case to distribute the observations evenly between the star-transits.

(*b*) Presents no difficulty.

(*c*) The pendulums are old ones, made of brass. An error of $\frac{1}{20}$ degree corresponds to one-millionth in the value of "*g*." The correction, as given in the tables, appears very large, sometimes exceeding 1,000 units,* but this is because the reduction is made to 0° C. The limits of temperature in the South African observations are about 12° to 24°, and it would be preferable to make the reduction to a standard temperature such as 20°, when its true value would be apparent. When working in a cellar there is no difficulty in finding the temperature correctly to $\frac{1}{20}$ degree or less. At the same time it would be much better to use pendulums of invar.

* The unit is the seventh decimal of the (single) period in seconds. It is about 1/5,080,000 part in the period or 1/2,540,000 in "*g*."

Two thermometers were provided, of which one (No. 53) was used throughout. It had been standardised in 1894 and again in 1895. It was expected that no further change could occur after the first few years, and unfortunately the author neglected to standardise it again till August, 1910, when it was found to have changed very much (see table, p. 90). It was tested by a thermometer (P.T.R. 28,629) possessing the 0° and 100° points, and these were found correct. The results given below are according to the 1910 standarisation.

(*d*) There is no difficulty in finding the density of the air with sufficient accuracy. This correction depends, therefore, only on the accuracy of the formula given by Sterneck, according to which the period varies by an amount proportional to the change of density. For corrections *c* and *d* the values obtained in Austria* have been used, viz.:—

49·26 units (sidereal time) per 1° C.
542·0 ,, ,, ,, for a change of density equal to the density of air at normal temperature and pressure. The pressure correction might be eliminated by swinging the pendulum *in vacuo*, did the apparatus permit.

(*e*) This correction is by far the most difficult. It consists of two parts—the oscillation of the pendulum support, and that of the pillar or wall on which the support is placed. With regard to the former, it is assumed that the correction is always the same, and therefore disappears in comparative measurements. The stability of the pillar or wall is tested by giving it ten properly timed blows with a wooden rod which has been pressed against a spring with a force of 5 kilogs. If the succession of blows does not induce a measureable amplitude of swing in the pendulum it is assumed that the effect of vibration of the pillar is negligible. More satisfactory methods have been worked out of late, but they involve the use of different patterns of apparatus (stands carrying more than one pendulum at a time), and so could not be used.

From this review of the corrections it might be supposed that when working under favourable conditions the results should agree to within 5 units. Experience shows that this is not the case. Even at a well-equipped observatory, such as that of Pola, differences of 20 units are often noticed, and on repeating the observations after an interval, much more. The same is true of the South African measurements—a fact which long puzzled and disconcerted the present writer. The larger differences may be due to secular changes of length in the pendulums, but this would not account for the irregular variations from day to day. Eventually a cause for this was found in variations in

* Veröff. Hydrog. Amts. der K. K. Kriegsmarine, No. 7, p. 1. Pola, 1898.

strength of the current used to work the electromagnet of the coincidence apparatus.

In the Sterneck apparatus a flash is produced each time the current is made or broken by the clock: there are thus two independent series of flashes, either of which may be used to determine the coincidence period. Unfortunately, before the influence of current variation was thought of, no record was kept as to whether the make or break was used. The influence of current variation is much greater on make than on break, but is still perceptible on the latter, as certain special observations showed. A set of 10 coincidences was observed with the aid of current from two accumulators, which remained practically steady at $9\frac{1}{2}$ (arbitrary units); the battery was then exchanged for three leclanches, which gave a current of $7\frac{1}{2}$ at first, falling to 6; with this another set was observed 25 coincidences later than the first. The accumulators were then restored and a third set taken, 50 coincidences later than the first. When observations were made by attraction of electromagnet ("make") the results were:—

Mean interval for 50 coincidences = 1549·31s. whence c = 30·9862
" " first 25 " = 776·22 " c = 31·0488

The first value of c is the true one, the second is lengthened because the current was weakened and the electromagnet pulled over more slowly in the second half of the observations than in the first. The real delay in the action of the magnet is given by $776{\cdot}22 - \frac{1549{\cdot}31}{2} = 1{\cdot}67$; this is about $\frac{1}{2\,0}$ coincidence, and indicates a delay of $\frac{1}{2\,0}$ period of pendulum, or $\frac{1}{4\,0}$ sec.

When the recovery of the spring ("break") was used, the result is much less inaccurate, although when the current is weak the spring recovers a little quicker. Similar observations gave—

Mean interval for 50 coincidences = 1549·47s. whence c = 30·9894
" " first 25 " = 774·57 " c = 30·9828

i.e., the recovery of the magnet is accelerated by—

$$\frac{1549{\cdot}47}{2} - 774{\cdot}57 = {\cdot}16 \text{ or } \tfrac{1}{2\,0\,0} \text{ coincidence, or by } \tfrac{1}{4\,0\,0} \text{ sec.}$$

The effect of these errors would be to make the calculated period of the pendulum too short by 70 units and too long by 7 units respectively.

It seems probable that there may be some change in length of the pendulums also. No. 23 gives results that are notably more irregular than the other two, though no defect in it could be discovered.

To summarise, we may say that the chief sources of error in the experiment, and kinds of error they give rise to, are :—

Irregularity in rate of clock	Diurnal.
Variation of temperature	Diurnal.
Unsteadiness of support	Local.
Change in Length	Secular.
Change in strength of current	Irregular.

RESULTS.

	Johannesburg.		Vereeniging.	Cape of Good Hope Observatory.	Lourenço Marques.	Pola.
	School o Mines.	Observatory.				
	0·50					
Period of 23	—	85315	—	82409	83977	79970
,, 44	—	88974	—	86109	87627	83694
,, 62	81833	81870	81522	79038	80536	76642
Diff. 44—23	—	3659	—	3700	3650	3724
,, 44—62	—	7104	—	7071	7091	7052
Diff. from Pola 23	—	5345	—	2449	4007	—
,, ,, 44	—	5280	—	2306	3933	—
,, ,, 62	5191	5228	4880	2385	3894	—
Mean	—	5284	—	2413	3945	—
Corresponding difference in "g"	2004	2040	1884	931	1523	—
"g" observed	9·78638	9·78602	9·78758	9·79711	9·79119	9·80642
"g" calc. at sea-level	9·79011	9·79011	9·79046	9·79618	9·79001	9·80584
Correction for altitude	− 538	− 556	− 442	− 5	− 17	− 9
,, strata	+ 193	+ 195	+ 160	− 2	+ 4	+ 3
"g" calc.	9·78666	9·78650	9·78764	9·79611	9·78988	9·80578
Anomaly	− 28	− 48	− 6	+ 100	+ 131	+ 64

The above table gives a summary of the observations taken at the stations described. The concordance of the measurements is not as good as might be wished, and it seems probable that some secular change in the pendulums is the cause of this. Accordingly the old observations at Pola may not be properly comparable with those in South Africa, and it would be well to swing the pendulums again at Pola. The absolute values of the anomaly may therefore be wrong; at the same time the general character of it is unmistakable, and there seems no reason to doubt the values found for the difference between sea-level and the plateau. Probably the most trustworthy of all the observations are those at Lourenço Marques and Johannesburg Observatories. These were both done under favourable conditions, and within a month of one another; and as the difference in latitude is trifling, the effect of level stands out with special clearness. The difference in anomaly is between + 131 and − 36 or 177 units, pointing, as far as one can see, to a greater density of rock in the lower strata near sea-level than on the plateau.

The result may be put in this form :—

"g" Lourenço Marques – "g" Johannesburg = + 517
Difference due to latitude..... ..... = – 10
∴ Difference due to altitude (1805 m.) ..... = + 527

or 3·4 metres per unit (10^{-5} m./sec.^{2}). The comparison between Lourenço Marques and Vereeniging gives practically the same. This quantity has usually been stated as 5 metres.

An explanation of this, suggested to the writer by Prof. Schwarz, is that the South African plateau is a sort of floating island of lighter rock, the roots of which go down to a depth at which the rock in most regions is denser (of basic material)—something like an ice-floe on water. The suggestion is quite a possible one physically, and it is easy to adjust the arithmetic to it. Thus, supposing the defect in density for a depth of 10 kilometres below sea-level were about 0·5, or if the deficiency were less, but extended to a greater depth, the anomaly in "g" would be accounted for.

CALIBRATION OF THERMOMETER **53.**

Reading in cm.	Temperature Centigrade.		
	1894.	1895.	1910.
8	8·85	8·60	8·61
9	10·49	10·25	10·18
10	12·10	11·92	11·75
11	13·73	13·55	13·32
12	15·31	15·20	14·89
13	16·94	16·82	16·46
14	18·51	18·40	18·03
15	20·10	20·00	19·60
16	21·71	21·62	21·17
17	23·27	23·20	22·74
18	24·84	24·80	24·31

The last column is equivalent to the equation—

$$t = -3{\cdot}95 + 1{\cdot}57\,x.$$

The observations in the tables were reduced by the 1895 calibration. The final results (p. 89) are then corrected to 1910 values.

Remarks to Tables.

The intervals given are for 100 coincidences in the observations at Johannesburg (Telephone Tower), 50 in the other cases.

The amplitude of swing is expressed in scale divisions, each division being approximately 3 mm. The distance from scale to mirror and back to telescope (doubled distance) is measured, and allows of reducing the scale divisions to minutes of arc.

When a mean-time clock or chronometer was used, its rate was expressed by stating the ratio of the length of its second to that of the sidereal clock with which it was compared.

c = period of coincidence.

$$s = \frac{c}{2c - 1} = \text{period of pendulum.}$$

When a mean-time clock or chronometer was used, the value of s found by it is converted to the value in terms of the sidereal clock before recording in the tables.

u = correction for rate of sidereal clock.
a = amplitude.
t = temperature.
d = density of air.
S = corrected period of pendulum.

S is subsequently corrected for the new calibration of thermometer **53** by the following amounts:—

At Johannesburg (Telephone Tower)	+ 5 units
Vereeniging	+ 17 ,,
Cape of Good Hope	+ 20 ,,
Lourenço Marques	+ 17 ,,
Johannesburg Observatory	+ 14 ,,

Sidereal clock rates:—

Johannesburg (Telephone Tower) ...	0·25s./day gaining
Vereeniging	0·06s./day losing
Cape of Good Hope	0·15s./day losing

Johannesburg Observatory. Sidereal clock gaining 2·32s./day. Riefler (mean) losing 2·32s./day, *cf.* to sidereal. Hence Riefler rate was correct.

TABLES.

Date, 20.7.08.
Place: Basement of Telephone Tower, Johannesburg.
Pendulum No. **62**.
Thermometer No. **53**, 9·03 to 9·10 = 10·36° Cent.
Barometer, 629·2.
Amplitude, 10·0 to 7·1 = 23·2′.
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
9	22	29·8	10	23	52·2	3682·4
	23	7·1		24	30·2	3·1
	23	43·3		25	5·8	2·5
	24	20·4		25	44·0	3·6
	24	56·9		26	19·2	2·3
	25	34·2		26	57·5	3·3
	26	10·6		27	33·2	2·6
	26	48·1		28	11·0	2·9
	27	24·3		28	47·0	2·7
	28	1·9		29	24·6	2·7

Mean ..... 3682·81

$c = 36{\cdot}8281$
$2c - 1 = 72{\cdot}6562$ } mean time

s =	0·5082736	sidereal
u =	− 14	
a =	− 14	
t =	− 510	
d =	− 432	
S =	0·5081766	

Date, 20.7.08.
Place: Basement of Telephone Tower, Johannesburg.
Pendulum No. **62.**
Thermometer No. **53,** 9·10 to 9·10 = 10·42° Cent.
Barometer, 629·2.
Amplitude, 7·1 to 5·2 = 16·7′.
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
10	23	52·2	11	25	11·9	3679·7
	24	30·2		25	50·0	9·8
	25	5·8		26	25·5	9·7
	25	44·0		27	3·6	9·6
	26	19·2		27	38·9	9·7
	26	57·5		28	17·5	80·0
	27	33·2		28	52·3	79·1
	28	11·0		29	30·8	9·8
	28	47·0		30	6·1	9·1
	29	24·6		30	44·6	80·0

Mean ..... 3679·65

c = 36·7965 } mean time
$2c-1$ = 72·5930 }

s = 0·5082798 sidereal
u = − 14
a = − 7
t = − 513
d = − 432

S − 0·5081832

Date, 20.7.08.
Place : Basement of Telephone Tower, Johannesburg.
Pendulum No. **62.**
Thermometer No. **53,** 9·19 to 9·21 = 10·60° Cent.
Barometer, 628·6.
Amplitude, 10·5 to 7·2 = 23·0′.
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
2	21	33·8	3	22	53·0	3679·2
	22	10·2		23	29·7	9·5
	22	47·5		24	6·4	8·9
	23	24·0		24	42·8	8·8
	24	0·9		25	20·1	9·2
	24	37·6		25	56·5	8·9
	25	14·4		26	33·6	9·2
	25	51·0		27	10·3	9·3
	26	28·0		27	47·5	9·5
	27	4·8		28	24·0	9·2

Mean ..... 3679·17

$c = 36{\cdot}7917$
$2c-1 = 72{\cdot}5834$ } mean time

$s' =$ 0·5082807 sidereal
$u =$ − 14
$a =$ − 14
$t =$ − 522
$d =$ − 431

S = 0·5081826

Date, 20.7.08.
Place : Basement of Telephone Tower, Johannesburg.
Pendulum No. **62.**
Thermometer No. **53,** 9·20 to 9·22 = 10·62° Cent.
Barometer, 628·6.
Amplitude, 7·4 to 5·0 = 16·8′.
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
3	22	53·0	4	24	10·9	3677·9
	23	29·7		24	47·5	7·8
	24	6·4		25	24·8	8·4
	24	42·8		26	0·8	8·0
	25	20·1		26	38·2	8·1
	25	56·5		26	14·7	8·2
	26	33·6		27	51·9	8·3
	27	10·3		28	28·3	8·0
	27	47·5		29	5·6	8·1
	28	24·0		29	42·0	8·0

Mean ..... 3678·08

$c = 36{\cdot}7808$
$2c-1 = 72{\cdot}5616$ } mean time

$s =$ 0·5082837 sidereal
$u =$ − 14
$a =$ − 7
$t =$ − 523
$d =$ − 431

S = 0·5081862

Date, 20.7.08.
Plate : Basement of Telephone Tower, Johannesburg.
Pendulum No. **62.**
Thermometer No. **53,** 9·16 to 9·21 = 10·58° Cent.
Barometer, 629·2.
Amplitude, 10·4 to 7·2 = 22·9′
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
8	22	47·0	9	24	4·9	3677·9
	23	23·6		24	41·9	8·3
	24	0·6		25	18·8	8·2
	24	37·1		27	55·3	8·2
	25	14·1		26	32·2	8·1
	25	50·7		27	8·9	8·2
	26	27·4		27	46·1	8·7
	27	4·3		28	22·5	8 2
	27	41·1		28	59·6	8·5
	28	17·9		29	36·1	8·2

Mean ..... 3678·25

c = 36·7825
$2c-1$ = 72·5650
} mean time

s' = 0·5082823 sidereal
u = − 14
a = − 14
t = − 521
d = − 432

S = 0·5081842

Date, 20.7.08.
Place : Basement of Telephone Tower, Johannesburg.
Pendulum No. **62.**
Thermometer No. **53,** 9·21 to 9·27 = 10·66° Cent.
Barometer, 629·2.
Amplitude, 7·4 to 5·0 = 16·8′.
Doubled Distance, 3·8.
Rate of Clock (Carroll), 1·0027463.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
9	24	4·9	10	25	22·8	3677·9
	24	41·9		16	1·1	9·2
	25	18·8		26	37·0	8·2
	25	55·3		27	13·9	8·6
	26	32·2		27	50·6	8·4
	27	8·9		28	27·0	8·1
	27	46·1		29	4·0	7·9
	28	22·5		29	40·7	8·2
	28	59·6		30	17·8	8·2
	29	36·1		30	54·5	8·4

Mean ..... 3678·31

$c = 36{\cdot}7831$
$2c-1 = 72{\cdot}5662$ } mean time

$s =$ 0·5082822 sidereal
$u =$ − 14
$a =$ − 7
$t =$ − 527
$d =$ − 432

S = 0·5081842

Date, 4.10.08.
Place : Vereeniging Post Office.
Pendulum No. **62.** No cover.
Thermometer No. **53,** 13·41 to 13·51 = 14·46 = 17·55° Cent.
Barometer, 645·4.
Double Distance, 3·4 m.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
11	1	22·1	11	31	59·5	1837·4
	1	59·3		32	37·1	7·8
	2	35·8		33	12·8	7·0
	3	13·0		33	50·7	7·7
	3	49·1		34	26·4	7·3
	4	27·0		35	4·1	7·1
	5	2·6		35	39·7	7·1
	5	40·4		36	18·0	7·6
	6	16·1		36	53·0	6·9
	6	54·0		37	31·3	7·3

Mean ..... 1837·32

c = 36·7464
$2c-1$ = 72·4928
} mean time

s = 0·5082822 sidereal
u = + 4
a = − 18
t = − 864
d = − 429

S = 0·5081515

Date, 4.10.08.
Place : Vereeniging Post Office.
Pendulum No. **62.** No cover.
Thermometer No. **53,** 13·41 to 13·71 = 13·56 = 17·70° Cent.
Barometer, 640·4.
Amplitude, 7·8 to 6·5 = 7·15 = 21·8′.
Doubled Distance, 3·4 m.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
11	31	59·5	12	2	36·8	1837·3
	32	37·1		3	15·3	8·2
	33	12·8		3	50·2	7·4
	33	50·7		4	29·0	8·3
	34	26·4		5	4·0	7·6
	35	4·1		5	42·4	8·3
	35	39·7		6	17·6	7·9
	36	18·0		6	56·0	8·0
	36	53·0		7	31·2	8·2
	37	31·3		8	9·9	8·6

Mean ..... 1837·98

$c = 36{\cdot}7596$
$2c-1 = 72{\cdot}5192$ } mean time

$s =$ 0·5082798 sidereal
$u =$ + 4
$a =$ − 13
$t =$ − 872
$d =$ − 429

S = 0·5081488

Date, 4.10.08.
Place: Vereeniging Post Office.
Pendulum No. **62.**
Thermometer No. **53,** 13·92 to 14·22 = 14·07 – 18·51° Cent.
Barometer, 638·6.
Amplitude, 10·0 to 8·0 = 9·0 = 27·2′.
Doubled Distance, 3·4 m.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
12	53	37·8	13	24	14·1	1836·3
		14·0			50·6	·6
		51·1			27·9	·8
		27·9			04·0	·1
		04·7			40·9	·2
		41·0			17·9	·9
		18·1			54·3	·2
		54·5			31·1	·6
		31·6			07·8	·2
		08·0			44·6	·6

Mean ..... 1836·45

$c = 36{\cdot}7290$
$2c-1 = 72{\cdot}4580$ } mean time

$s' = 0{\cdot}5082856$ sidereal
$u = + 4$
$a = - 19$
$t = - 912$
$d = - 426$

$S = 0{\cdot}5081503$

Date, 4.10.08.
Place: Vereeniging.
Pendulum No. **62.**
Thermometer No. **53,** 14·11 to 14·33 = 14·22 = 18·75° Cent.
Barometer, 638·6.
Amplitude, 8·3 to 6·8 = 7·55 = 23·0′.
Doubled Distance, 3·4.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
13	24	14·1	13	54	50·5	1836·4
		50·6			27·6	7·0
		27·9			04·0	6·1
		04·0			40·7	6·7
		40·9			17·4	6·5
		17·9			54·2	6·3
		54·3			30·9	6·6
		31·1			07·9	6·8
		07·8			44·6	6·8
		44·6			21·5	6·9

Mean ..... 1836·61

c = 36·7322 } mean time
$2c-1$ = 72·4644 }

s = 0·5082850 sidereal
u = + 4
a = − 14
t = − 924
d = − 426

S = 0·5081490

Date, 4.10.08.
Place: Vereeniging Post Office.
Pendulum No. **62.**
Thermometer No. **53,** 14·45 to 15·08 = 14·76 = 19·69° Cent.
Barometer, 638·3.
Amplitude, 10·0 to 7·9 = 8·95 = 27·1′.
Doubled Distance, 3·4 m.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
14	55	26·2	15	26	00·6	1834·4
		03·1			37·3	4·2
		39·5			13·7	4·2
		16·4			50·7	4·3
		52·7			26·8	4·1
		30·0			04·4	4·4
		06·1			40·0	3·9
		43·5			18·0	4·5
		19·6			52·9	3·3
		57·0			31·3	4·3

Mean ..... 1834·16

c = 36·6832 } mean time
$2-c1$ = 72·3664 }

s' = 0·5082942 sidereal
u = + 4
a = − 19
t = − 970
d = − 425

S = 0·5081532

Date, 4.10.08.
Place: Vereeniging Post Office.
Pendulum No. **62.**
Thermometer No. **53,** 15·00 to 15·14 = 15·07 = 20·11° Cent.
Barometer, 638·3.
Amplitude, 8·4 to 6·6 = 7·5 = 22·8′.
Doubled Distance, 3·4 m.
Rate of Clock (Carroll), 1·0027324.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
15	26	00·6	15	56	34·9	1834·3
		37·3			11·9	4·6
		13·7			48·0	4·3
		50·7			25·1	4·4
		26·8			01·7	4·9
		04·4			38·3	3·9
		40·0			15·0	5·0
		18·0			51·9	3·9
		52·9			28·5	5·6
		31·3			05·3	4·0

Mean ..... 1834·49

c = 36·6898 } mean time
$2c-1$ = 72·3796 }

s =	0·5082929	sidereal
u =	+ 4	
a =	− 14	
t =	− 991	
d =	− 424	
S =	0·5081504	

Date, 17.1.10.
Place: Royal Observatory, Cape of Good Hope.
Pendulum No. **23.** No cover.
Thermometer No. **53,** 16·38 to 16·36 = 22·21° Cent.
Barometer (Aneroid), 755·2.
Amplitude, $\left\{\begin{matrix}10{\cdot}0\\8{\cdot}8\end{matrix}\right\}$ to $\left\{\begin{matrix}9{\cdot}0\\7{\cdot}8\end{matrix}\right\}$ = 8·9 = 30·3′.
Doubled Distance, 3·0 m.
Rate of Clock (Carroll), 1·0028600.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
12	17	20·0	12	47	43·4	1823·4
		56·9			22·0	4·9
		32·8			56·3	3·5
		10·0			35·0	5·0
		45·6			09·2	3·6
		23·0			48·0	5·0
		58·5			22·0	3·5
		36·0			01·3	5·3
		11·4			34·8	3·4
		49·1			14·5	5·4

Mean ..... 1824·30

$c = 36{\cdot}4860$
$2c-1 = 71{\cdot}9720$ } mean time

s =	0·5083971 sidereal
u =	+ 17
a =	− 25
t =	− 1094
d =	− 498
S =	0·5082371

Date, 17.1.10.
Place : Roy. Obs. C. G. H.
Pendulum No. **44**.
Thermometer No. **53**, 16·50 to 16·44 = 22·36° Cent.
Barometer, 755·0.
Amplitude, $\left\{\begin{matrix}8{\cdot}8\\8{\cdot}8\end{matrix}\right\}$ to $\left\{\begin{matrix}8{\cdot}1\\8{\cdot}1\end{matrix}\right\}$ = 8·45 = 28·7′.
Doubled Distance, 3·0
Rate of Clock (Carroll), 1·0028755.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
14	17	30·0	14	46	24·9	1734·9
		05·2			00·3	5·1
		39·4			34·4	5·0
		14·6			09·7	5·1
		48·8			43·8	5·0
		23·9			19·1	5·2
		58·2			53·2	5.0
		33·3			28·7	5·4
		08·4			02·6	4·2
		42·6			38·0	5·4

Mean ..... 1735·03

c = 34·7006
$2c-l$ = 68·4012
} mean time

s =	0·5087685 sidereal
u =	+ 17
a =	− 23
t =	− 1102
d =	− 497
S =	0·5086080

Date, 17.1.10.
Place : Roy. Obs. C. G. H.
Pendulum No. **62.**
Thermometer No. **53**, 16·46 to 16·42 = 22·32° Cent.
Barometer, 754·7.
Amplitude, 8·6 to 8·0 = 8·3 = 28·3′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028790.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
16	8	43·9	16	40	41·3	1917·4
		22·4			20·0	·6
		00·6			58·0	·4
		39·0			36·8	·8
		17·2			14·8	·6
		55·7			53·6	·9
		34·0			31·2	·2
		12·4			09·4	·0
		50·6			48·0	·4
		29·2			27·0	·8

Mean ..... 1917·51

c = 38·3502
$2c-l$ = 75·7004 } mean time

s =	0·5080635	sidereal
u =	+ 17	
a =	− 22	
t =	− 1100	
d =	− 497	
S =	0·5089033	

Date, 17.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. **62**.
Thermometer No. **53**.
Barometer, 754·9.
Amplitude, 8·9 to 8·1 = 8·5 = 28·9′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028740.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
18	2	17·4	58	34	15·0	1917·6
		56·1			54·8	8·7
		34·1			31·9	7·8
		13·0			11·0	8·0
		50·9			48·5	7·6
		29·9			27·8	7·9
		07·4			05·4	8·0
		46·5			44·5	8·0
		24·3			22·0	7·7
		03·5			01·3	7·8

Mean ..... 1917·91

c = 38·3582
$2c-1$ = 75·7164 } mean time

s =	0·5080595	sidereal
u =	+ 17	
a =	− 23	
t =	− 1088	
d =	− 497	
S =	0·5089004	

Date, 17.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. **44.**
Thermometer No. **53,** 16·30 to 16·24 = 22·05° Cent.
Barometer, 755·3.
Amplitude, 9·2 to 8·6 = 8·9 = 30·0′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028700.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
20	7	29·4	20	36	23·6	1734·2
		04·2			58·4	·2
		38·7			33·1	·4
		13·5			07·7	·2
		48·2			42·5	·3
		22·7			17·0	·3
		57·5			52·0	·5
		32·3			26·3	·0
		07·0			01·4	·4
		41·5			35·7	·2

Mean ..... 1734·27

c = 34·6854 } mean time
$2c-1$ = 68·3708 }

s = 0·5087690 sidereal
u = + 17
a = − 25
t = - 1086
d = − 498

S = 0·5086098

Date, 17.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. **23.**
Thermometer No. **53,** 16·07 to 16·02 = 21·70° Cent.
Barometer, 756·5.
Amplitude, 8·2 to 7·2 = 7·7 = 26·2′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028685.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
21	54	05·7	22	24	31·1	1825·4
		42·2			07·3	·1
		18·6			44·0	·4
		55·1			20·2	·1
		31·6			57·1	·5
		08·0			33·1	·1
		44·7			10·3	·6
		21·0			46·0	·0
		58·0			23·5	·5
		34·0			59·0	·0

Mean ..... 1825·27

c = 36·5054
$2c-1$ = 72·0108 } mean time

s = 0·5083976 sidereal
u = + 17
a = − 19
t = − 1069
d = − 499

S = 0·5082406

Date, 18.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. 23.
Thermometer No. 53, 15·90 to 15·90 = 21·46° Cent.
Barometer, 756·8.
Amplitude, 8·1 to 7·1 = 7·6 = 25·9′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028660.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
7	9	11·1	7	39	38·0	1826·9
		47·3			13·1	5·8
		24·2			51·2	7·0
		00·3			26·0	5·7
		37·4			04·4	7·0
		13·3			39 0	5·7
		50·4			17·6	7·2
		26·4			52·0	5·6
		03·6			30·8	7·2
		39·4			05·0	5·6

Mean ..... 1826·37

$c = 36{\cdot}5274$
$2c-1 = 72{\cdot}0548$ } mean time

$s' = 0{\cdot}5083920$ sidereal
$u = + 17$
$a = - 18$
$t = - 1057$
$d = - 500$

$S = 0{\cdot}5082372$

Date, 18.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. **23.**
Thermometer No. **53,** 16·00 to 16·00 = 21·62° Cent.
Barometer, 757·1.
Amplitude, 8·1 to 7·1 = 7·6 = 25·9′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028650.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
9	3	26·2	9	33	51·2	1825·0
		02·2			26·3	4·1
		39·3			04·2	4·9
		15·0			39·3	4·3
		52·3			17·1	4·8
		28·0			52·3	4·3
		05·4			30·2	4·8
		41·0			05·4	4·4
		18·4			43·4	5·0
		54·0			18·2	4·2

Mean ..... 1824·58

$$\left.\begin{aligned} c &= 36{\cdot}4916 \\ 2c-1 &= 71{\cdot}9832 \end{aligned}\right\} \text{mean time}$$

s =	0·5083985	sidereal
u =	+ 17	
a =	= 18	
t =	= 1065	
d =	− 500	
S =	0·5082419	

Date, 18.1.10.
Place: Roy. Obs. C. G. H.
Pendulum No. 23.
Thermometer No. 53, 16·15 to 16·13 = 21·84° Cent.
Barometer, 756·6.
Amplitude, 8·1 to 7·3 = 7·7 = 26·2′.
Doubled Distance, 3·0.
Rate of Clock (Carroll), 1·0028640.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
11	1	12·6	11	31	38·0	1825·4
		49·0			14·2	·2
		25·6			51·0	·4
		02·1			27·2	·1
		38·7			04·0	·3
		15·0			40·2	·2
		51·8			17·0	·2
		28·0			53·2	·2
		04·9			29·9	·0
		41·0			06·3	·3

Mean ..... 1825·23

c = 36·5046 } mean time
$2c-1$ = 72·0092 }

s = 0·5083954 sidereal
u = + 17
a = − 19
t = − 1076
d = − 499

S = 0·5082377

Date, 11.7.10.
Place: Observatory, Lourenço Marques.
Pendulum No. 62.
Thermometer No. 53, 14·76 to 14·74 = 19·60° Cent.
Barometer, 762·0.
Amplitude, 9·2 to 8·4 = 8·8 = 28·3'.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145 s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
6	3	33·7	6	29	23·2	1549·5
		04·9			54·5	·6
		35·8			25·2	·4
		07·0			56·5	·6
		37·8			27·3	·5
		09·0			58·6	·6
		39·8			29·1	·3
		11·0	Minute signal of clock interfered			
		41·7			31·2	·5
		12·9			02·5	·6

Mean ..... 1549·51

c = 30·9902 } mean time
$2c-1$ = 60·9804 }

s = 0·5081994 sidereal
u = + 9
a = − 21
t = − 966
d = − 507

S = 0·5080509

Date, 11.7.10.
Place : Observatory, Lourenço Marques.
Pendulum No. **44.**
Thermometer No. **53,** 14·73 to 14·72 = 19·56° Cent.
Barometer, 760·6.
Amplitude, 8·6 to 8·0 = 8·3 = 26·7′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
8	7	39·2	8	31	27·2	1428·0
		08·1			56·3	8·2
		36·4			24 4	8·0
		05·3			53·4	8·1
		33·3			21·6	8·3
		02·2			50·6	8·4
		30·6			18 7	8·1
		59·2			47·8	8·6
		27·6			15·8	8·2
		56·7			44·7	8·0

Mean ..... 1428·15

$c = 28{\cdot}5630$
$2c-1 = 56{\cdot}1260$ } mean time.

$\frac{1}{3} = 0{\cdot}5089083$ sidereal
$u = + 9$
$a = - 19$
$t = - 964$
$d = - 506$

$S = 0{\cdot}5087603$

Date, 11.7.10.
Place : Observatory, Lourenço Marques.
Pendulum No. **23.**
Thermometer No. **53,** 14·78 to 14·80 = 19·67° Cent.
Barometer, 760·5.
Amplitude, 8·9 to 8·1 = 8·5 = 27·4′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
10	9	16·8	10	34	04·8	1488·0
		46·8			34·8	8·0
		16·4			04·2	7·8
		46·4			34·3	7·9
		15·9			03·7	7·8
		46·0			33·9	7·9
		15·4			03·1	7·7
		45·4			33·4	8·0
		14·9			02·8	7·9
		45·0			32·9	7·9

Mean ..... 1487·89

c = 29·7578 } mean time
$2c-1$ = 58·5156 }

s = 0·5085448 sidereal
u = + 9
a = − 20
t = − 968
d = − 505

S = 0·5083964

Date, **11.7.10.**
Place: **Observatory, Lourenço Marques.**
Pendulum No. **23.**
Thermometer No. **53,** 14·80 to 14·80 = 19·68° Cent.
Barometer, 760·5.
Amplitude, 8·9 to 8·0 = 8·45 = 27·2′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
12	9	19·3	12	34	07·3	1488·0
		49·1			37·2	8·1
		18·8			06·8	8·0
		48·7			36·9	8·2
		18·3			06·3	8·0
		48·2			36·4	8·2
		17·9			05·8	7·9
		47·9			36·0	8·1
		17·5			05·4	7·9
		47·4			35·5	8·1

Mean ..... 1488·05

c = 29·7610 } mean time
$2c-1$ = 58·5220 }

s = 0·5085437 sidereal
u = + 9
a = − 20
t = − 969
d = − 505

S = 0·5083952

Date, 11.7.10.
Place: Observatory, Lourenço Marques.
Pendulum No. 44.
Thermometer No. 53, 14·83 to 14·82 = 19·72° Cent.
Barometer, 760·7.
Amplitude, 9·2 to 8·2 = 8·7 = 28·0′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145 s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
14	3	54·9	14	27	42·5	1427·6
		24·0			11·8	7·8
		52·0			39·6	7·6
		21·0			08·9	7·9
		48·9			36·8	7·9
		18·1			06·0	7·9
		46·2			33·8	7·6
		15·4			03·2	7·8
		43·3			30·9	7·6
		12·5			00·0 (?)	7·5

Mean ..... 1427·74

c = 28·5548 } mean time
$2c-1$ = 56·1096 }

s = 0·5089112 sidereal
u = + 9
a = − 21
t = − 971
d = − 506

S = 0·5087623

Date, 11.7.10.
Place : Observatory, Lourenço Marques.
Pendulum No. **62.**
Thermometer No. **53,** 14·85 to 14·87 = 19·78° Cent.
Barometer, 761·4.
Amplitude, 8·8 to 7·8 = 8·3 = 26·7′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
16	14	04·2	16	39	53·4	1549·2
		35·6			24·5	8·9
		06·3			55·4	9·1
		37·5			26·5	9·0
		08·2			57·3	9·1
		39·5			28·4	8·9
		10·1			59·6 (?)	9·5
		41·5			30·4	8·9
		12·1			01·0 (?)	8·9
		43·4			32·3	8·9

Mean ..... 1549·00

$c = 30{\cdot}9800$ } mean time
$2c-1 = 60{\cdot}9600$ }

s =	0·5082020	sidereal
u =	+ 9	
a =	− 19	
t =	− 974	
d =	− 506	
S =	0·5080530	

Date, 11.7.10.
Place: Observatory, Lourenço Marques.
Pendulum No. **62.**
Thermometer No. **53,** 14·82 to 14·82 = 19·71° Cent.
Barometer, 762·0.
Amplitude, 7·5 to 6·9 = 7·2 = 23·2′.
Doubled Distance, 3·20 m.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
18	14	33·6	18	40	22·9	1549·3
		04·8			54·0	9·2
		35·6			24·9	9·3
		06·7			56·0	9·3
		37·4			26·9	9·5
		08·7			58·0	9·3
		39·4			28·9	9·5
		10·7			—	—
		41·4			30·8	9·4
		12·7			02·0	9·3

Mean ..... 1549·34

c = 30·9868 } mean time.
$2c1-$ = 60·9736 }

s = 0·5082001 sidereal
u = + 9
a = − 14
t = − 971
d = − 507

S = 0·5080518

Date, 12.7.10.
Place : Observatory, Lourenço Marques.
Pendulum No. 44.
Thermometer No. 53, 14·55 to 14·53 = 19·26° Cent.
Barometer, 762·4.
Amplitude, 9·2 to 8·3 = 8·75 = 28·2′.
Doubled Distance, 3·20.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
1	58	09·3	2	21	57·9	1428·6
		38·0			26·3	·3
		06·6			54·8	·2
		35·3			23·6	·3
		03·9			52·1	·2
		32·1			20·6	·5
		01·0			49·2	·2
		29·5			17·8	·3
		58·0			46·3	·3
		26·6			14·9	3

Mean ..... 1428·32

c = 28 5664 } mean time.
$2c-1$ = 56·1328 }

s = ′ 0·5089072 sidereal
n = + 9
a = − 21
t = − 949
d = − 508

S = 0·5087603

Date, 12.7.10.
Place: Observatory, Lourenço Marques.
Pendulum No. **23.**
Thermometer No. **53,** 14·56 to 14·58 = 19·31° Cent.
Barometer, 763·1.
Amplitude, 8·4 to 7·8 = 8·1 = 26·0′.
Doubled Distance, 3·20.
Rate of Clock, 0·145s./day losing.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
1	5	05·9	4	29	54·0	1488·1
		35·9			23·9	·0
		05·3			53·5	·2
		35·4			23·6	·2
		04·8			53·0	·2
		34·9			23·0	·1
		04·5			52·7	·2
		34·5			22·6	·1
		03·9			52·2	·3
		34·0			22·1	·1

Mean ..... 1488·15

c = 29·7630 } mean time.
$2c-1$ = 58·5260 }

s = 0·5085432 sidereal
u = + 9
a = − 18
t = − 951
d = − 508

S = 0·5083964

Date, 21.7.10.
Place: Observatory, Johannesburg.
Pendulum No. 62.
Thermometer No. 53, 11·52 to 11·57 = 14·44° Cent.
Barometer, 620·45.
Amplitude, 10·2 to 9·2 = 97 = 19·2′.
Doubled Distance, 5·2.
Rate of Clock (Riefler mean time), correct = 1·0027379.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
11	9	19·7	11	39	53·1	1833·4
		56·0			29·2	3·2
		33·0			06·6	3·6
		09·2			42·5	3·3
		46·1			20·1	4·0
		22·5			55·8	3·3
		59·5			33·7	4·2
		35·8			09·2	3·4
		12·9			46·4	3·5
		49·4			22·6	3·2

Mean ..... 1833·51

c = 36·6702
$2c-1$ = 72·3404 } mean time

s = 0·5082997 sidereal
u = 0
a = − 10
t = − 711
d = − 420

S = 0·5081856

Date, 18.7.10.
Place: Observatory, Johannesburg.
Pendulum No. **44.**
Thermometer No. **53,** 11·48 to 11·40 = 14·28° Cent.
Barometer, 619·7.
Amplitude, 10·3 to 9·5 = 9·9 = 19·6′.
Doubled Distance, 5·2.
Rate of Clock (Riefler mean time), correct = 1·0027379.

Coincidences—

h.	m.	s.	h.	m.	s.	Diff.
12	15	37·8	12	43	23·7	1665·9
		10·0		—		—
		44·8		—		—
		16·8		45	02·0	5·2
		51·0			37·0	6·0
		23·6			08·6	5·0
		58·0			43·7	5·7
		30·1			15·3	5·2
		04·5			50·2	5·7
		36·7			21·9	5·2

Mean ..... 1665·49

c = 33·3098 } mean time
$2c-1$ = 65·6196 }

s = 0·5090094 sidereal
u = 0
a = − 10
t = −704
d = −420

S = 0·5088960

Date, 2.17.10.
Place : Observatory, Johannesburg.
Pendulum No. 23.
Thermometer No. 53, 11·62 to 11·67 = 14·62° Cent.
Barometer, 619·2.
Amplitude, 11·4 to 10·0 = 10·7 = 21·2′.
Doubled Distance, 5·2.
Rate of Clock (Riefler mean time), correct = 1·0027379.

Coincidences—

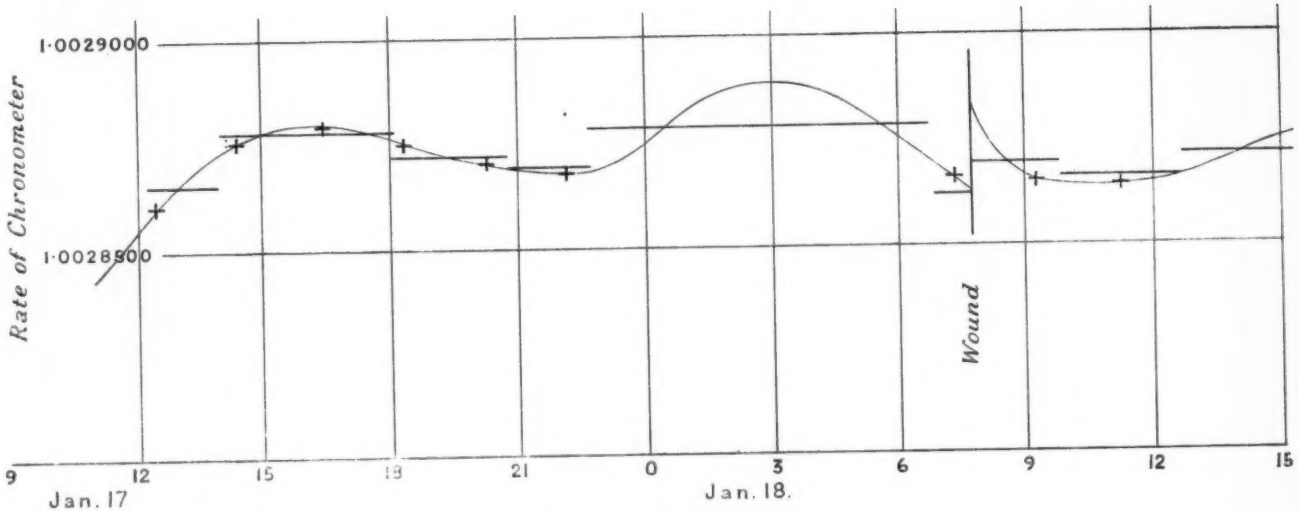
h.	m.	s.	h.	m.	s.	Diff.
13	46	18·0	14	15	25·7	1747·7
		52·2			59·8	·6
		27·8			35·5	·7
		02·4			09·7	·3
		37·8			45·7	·9
		12·2			20·0	·8
		47·8			55·4	·6
		22·2			29·8	·6
		57·8			05·2	·4
		32·2			39·7	·5

Mean ..... 1747·61.

$c = 34{\cdot}9522$ / mean time
$2c-1 = 68{\cdot}9044$ \

$s' = 0{\cdot}5086452$ sidereal
$u = 0$
$a = -12$
$l = -720$
$d = -419$

$S = 0{\cdot}5085301$



CAPE OF GOOD HOPE OBSERVATIONS.

EFFECTS OF UNIFORMITY AND CONTRAST ON LIGHT.

By Hermann Bohle, F.R.S.S.Af.

(Read August 17, 1910).

In the planning of houses, halls, schools, and factories a good deal of sinning takes place as regards the lighting. The architectural features of the buildings receive preference. The questions of comfort and of adequate light are given second place; and yet, for the welfare and comfort of the inhabitants, they are of vital importance. My remarks hold for day- and artificial light. Even in this country, with an almost eternal sunshine, one often finds rooms badly lighted even on the brightest days. Why? Too much daylight cannot be brought into a room. The human eye can adapt itself without harm to almost any daylight illumination, *as long as glare is avoided*, and pass from a room with an illumination of forty candle-metres to an outside one of forty thousand without effort.* There is therefore no reason for making the inside illumination small; it should certainly not be smaller than one-hundredth part of the outside one.

Glare must, however, be avoided. An exact definition of glare has never been given. Some people define it as the intrinsic brilliancy,† which, when it exceeds a certain value—a value which depends on the individual—causes dazzling and pain to the eye. This definition of glare is not sufficient. If we look at the filament of an incandescent electric lamp in the evening we experience a dazzling sensation, *or glare*, but if we do so during the day the glare does not occur, or is at least greatly diminished. But the light is there all the same. Again, if we place a light in front of a black wall and look at it the glare appears strongly, whereas if it is placed before a white screen the glare vanishes. We see that intrinsic brilliancy alone does not constitute glare, and that contrast

* A candle-metre denotes the illumination given by a standard candle on a perfectly white screen at a metre distance, assuming that all rays fall perpendicularly upon the screen.

† Intrinsic brilliancy is the ratio of the normal intensity, measured in candles to the surface of the source. As regards the latter we should take the apparent source.

plays an important part. In looking at a light before a dark screen the eye endeavours to do two things at once—the pupil tries to open wide to take in the dark background and to close up for the intrinsic brilliancy of the source. This phenomenon of double intentions really constitutes glare. The human eye tolerates enormous differences of diffused light, which we get from the light before a white screen, but it objects to high intrinsic brilliancy when it is accompanied by great contrasts such as a dark background.

A few remarks on the physiological effects of radiation may not be out of place.

The illuminants of old were of low power and great wave-length, the light being very red. With the advent of the gas mantle, the metal filament electric lamp, and the arc lamp, the light has become whiter and of much shorter wave-length. The lights of old were mostly too poor to enable people to work with artificial light; and this not being done, people suffered less from weak eyes than the present generation. Now the average person has to work three to four hours daily with artificial illumination, and it is therefore of the greatest importance that the work can be carried out with the least injury to the eyes. Many people have complained to me that electric light gives them headaches after an hour's working. They put it chiefly down to the high percentage of ultra-violet rays contained in the electric light. And yet daylight contains an even higher percentage of these rays, but it does not affect these persons.*

Without the slightest doubt modern illuminants have caused harm to the eyesight of many people. This is entirely due to improper illuminating engineering, whereby the destructive rays were given full scope, either by diffusing the light too little and causing simultaneous great contrasts or by directing the light wrongly. Even a small light—an ordinary wax candle—causes glare if it is directed into the eye under great contrasts. The eye attempts to do two things simultaneously. When contrasts are avoided the eye can protect itself. Moderate excesses are shut off by contraction of the pupil, sudden abnormal quantities of light by closing of the eyelids. Light has two different effects on the eye—the one is caused by the quantity, the other by the type of radiation.

Radiation is power. The light which enters the eye is absorbed and converted into heat. If the rate of conversion becomes too great the heating becomes excessive and the eyes give pain. If the "overheating" continues the eyes become inflamed and tears run. Was the time of overheating comparatively short, a few hours will see full recovery; otherwise, with continued excess absorption, the damage done may last

* I wish to point out here that the sunlight has an effect of this nature on me. By wearing, however, ordinary glasses (for shortsightedness) headaches practically disappear. An explanation will be given later on.

for weeks. Temporary blindness is also due to sudden excess light absorption.

Daylight, the best diffused of all, causes less injury by overheating than artificial light. In the latter the percentage of visible radiation is small, the ultra-red portion containing most. But the light obtained from modern illuminants is caused by temperature radiation—hence the amount of power which enters the eye from artificial lights is much greater than from an equivalent daylight illumination. The latter is based on luminescence or selective radiation, possesses therefore a higher percentage of visible radiation, and is less harmful. It is, of course, assumed that direct looking into the sun, or into reflected sunlight, is avoided.

The type of radiation is also of great importance. The effects caused begin with the blue radiation and continue up to the X-rays, the greatest effect being given by the extreme of the ultra-violet. The ultra-violet radiation extends far beyond the visible range. The visible part consists of long waves which are harmless as long as their intensity is limited. In artificial- and day-light they are moderately represented, and cause therefore little harm. The invisible portion may be divided into two sections—waves with a moderate frequency and such with high frequencies. The latter need hardly be considered here. They occur in a Geisler tube, but as the discharges take place within a glass tube the high-frequency waves are completely absorbed. They are also set up in a low-temperature mercury vapour arc, where they are again absorbed by the glass. Quartz does, however, not do so, and such lamps should therefore be avoided. In the high-temperature mercury vapour quartz lamp the high frequency ultra-violet rays do not occur.

Of greater importance are the rays of medium frequency, since they are set up in most modern illuminants. They are largely damped by clear glass. Consequently no one should look into a naked electric arc with the bare eye, as these rays are highly destructive. Moreover, the injury caused in this way is almost incurable. It is not external, but internal, and the eye loses the ability to keep anything in focus for any length of time.

Seeing that the ultra-violet rays are damaging to the eyesight we should guard against them. This can be done by the employment of proper globes. A mixture of red and green glass, giving a yellowish shade, will completely absorb the ultra-violet rays. Moreover, we should diffuse the light as much as possible, because by employing reflected light the ultra-violet rays are absorbed. It does not materially reduce the light, since the damaging ultra-violet rays take no part in giving light. As regards electric incandescent lighting, only such shades should be used which diffuse the light properly and obscure the lamp bulb. An advance

in this direction is shown in the prismatic glass shade, the so-called holophane shade, which diffuses the light well. It is, however, not deep enough to obscure the lamp bulb, so that the light should be out of the line of vision. It would even be an improvement to make the bulb itself of red-green glass.

When light is properly diffused the eye is not called upon to do two things simultaneously, *i.e.*, adapt itself to dark shadows and great intrinsic brilliancy at the same time. In wireless telegraphy, electric furnace work, electric welding, where naked arcs are employed, the operators should be protected by suitable glasses in order to prevent overheating and injury due to ultra-violet rays of medium frequency.

In taking once a number of students over some steel works at Sheffield we were shown, amongst other things, electric welding apparatus. As the number of protecting glasses was limited I looked for a few seconds with my naked eye at the arc, formed between the pieces to be welded together. The result was such injury to the eyes that they have not even fully recovered to-day. This was more than six years ago. I also remember waking up the following night with a maddening pain in my eyes, which felt as if they were full of pins and needles. It lasted for about an hour. Had I even worn ordinary clear glasses the effect would not have been so bad. In wearing glasses care should be taken that ultra-violet rays cannot enter the eye above or below the glasses.

Most people in this country will have experienced excessive glare at the seaside on sunny days. The illumination exceeds at noon often a hundred thousand candle-metres. The sunlight is largely reflected by the white sand, so that the intrinsic brilliancy is abnormally high. Moreover, the darkish sea provides a dark background, and glare is the result. Similar effects are shown in the Arctics, resulting finally in snow blindness. The latter may be avoided by the wearing of red and green glasses, as was proved by Sir Ernest Shackelton on his dash to the South Pole. Through glasses of this nature one may even look directly into the sun for minutes without harm. Headaches caused at the back of the eye by excess solar radiation or by artificial lights may also be prevented by the wearing of red and green glasses.

My remarks will have made the following points clear:—

(1) The illumination should be as uniform as possible.

(2) Direct light should be avoided.

(3) Naked lights should not be employed without adequate protection.

As regards (1), it is not difficult to produce a uniform illumination either during the day or at night.

Daylight can hardly be made excessive if glare is avoided. Nature has provided the eye with everything for its protection as long as glare does not occur. There is, therefore, from this standpoint nothing to be

said in favour of large rooms and small window space. Moreover, light has a stimulating effect on the system in general, and as regards germs of disease, light is one of the most powerful therapeutic agents we possess. Germs of disease live in the dark, and to live at all, darkness is essential to them, whereas light destroys them. Hence we should build our houses with large windows, without black coverings, and let the sun enter the house irrespective of the fading of carpets. Factories should be so constructed that the light can simply pour into the workrooms, with the avoidance of glare. For equal surface, skylights allow more light to enter than vertical windows. So-called shed roofs should, therefore, be glazed on the least sloping surface, whereas the reverse is invariably the case. For skin tuberculosis, the sun is one of the most powerful agents for cure. If the evil sits deeper, the application of X-rays, applied moderately, might produce beneficial results. At the same time, we must remember that X-rays are of very high frequency, and, if used excessively, might cause dissociation of the treated part.

This may be explained as follows:—

Take a substance of small atomic weight, such as Oxigon. It will respond or resonate with high frequencies, somewhere near the extreme end of the ultra-violet. If, on the other hand, we employ a heavier substance, the frequency must decrease before a response takes place. This applies, for instance, to heavy carbon compounds, which respond to the low frequencies of the long waves between the red and the yellow. Hence ultra-violet rays, *i.e.*, rays of high frequencies, must be harmful to plant life. The frequency is so great that the heavy groups of carbon cannot respond, but individual atoms may, and dissociation results. X-rays are even of higher frequency, and excess application must result in a dissociation of the treated parts.

Sun-burning is also due to excess exposure, but the skin protects the parts underneath and the stimulating effect largely counterbalances the discomfiture. Sun-baths are, therefore, highly to be recommended if applied in moderation. The same thing applies to electric baths, which will be found invigorating if excess is avoided.

After having dealt with the physiological effects of radiation, I shall consider how health and comfort may be obtained with artificial light.

Uniformity is again of great importance for preserving the eyesight. Clusters of lamps in the middle of a room should be avoided if possible. The arrangement of lamps distributed over the ceiling is preferable. It is, however, also more expensive on account of additional wiring. The uniformity becomes perfect by the application of indirect light. By means of shades the whole light of a number of distributed lights is thrown against the white ceiling from which it is reflected. About half the light is absorbed in this way, which constitutes a waste and the reason why

inverted lamps are not oftener employed. From a series of experiments I come, however, to the conclusion that the waste is more apparent than real. For the purpose of carrying out the tests I had six tantalum lamps fixed to a wooden frame in such a manner that they could easily be provided with all kinds of shades and also be inverted. The lamps, or rather the illumination, were then tested by means of an illumination photometer, (1) in a room with jet-black walls and ceiling, and afterwards in an office of slightly larger size with a white ceiling and light yellow walls. The results are shown in Fig. 1. We notice that the illumination increases as we pass from the dark to the light room, the difference being shown by the lengths of the ordinates lying between the curves (1) and (3). I expected a much greater increase, but as three sets of experiments yielded the same result a mistake seems improbable. The six lamps were then provided with holophane shades, whereby the illumination in the test plane (horizontal, 1 metre above floor) was further increased. Finally, the room was illuminated with 4–40-watt Osram lamps within long fancy shades, pointing upwards under an angle of 45°, 335 centimetres above the floor. The result was a uniform illumination of 13 candle-metres.

Tests were made in reading text-book print by means of the various illuminations.

In the dark room, an illumination of 35 to 40 candle-metres seemed essential for comfort. It was, however, necessary to keep the eye on the book, as roaming about caused glare. In the light room, where contrast was almost absent even with the lamps hanging downwards, 25 to 30 candle-metres seemed sufficient, and roaming about the room with the eyes did not cause glare as long as one did not look directly into the filament.

When the lamps were inverted, and a perfectly uniform illumination resulted, comfort was achieved even with such a low illumination as 13 candle-metres. Twenty candle-metres gave perfect results. Moreover, glare was entirely absent, as the bulbs were out of the line of vision. We see, therefore, that although by indirect lighting we waste light, the resulting uniformity requires less. Moreover, the eye may easily adapt itself to great differences in illumination if the latter be uniform. I have seen it frequently stated lately that the human eye objects to an artificial illumination of more than 80 to 100 candle-metres. I do not agree with this. The eye, according to my own experience, will stand an enormous illumination if the latter is thoroughly diffused and contrasts are avoided. If we could get daylight diffusion, and prevent contrast, the eye would stand thousands of candle-metres without harm.

Let us try to form a reason for the reduction in light required with an increase in uniformity, or rather with the avoidance of contrasts.*

* Curve 3 in Fig. 1, which was taken in the light room, does not show such a very great increase in the uniformity of the light. Contrast had, however, almost disappeared.

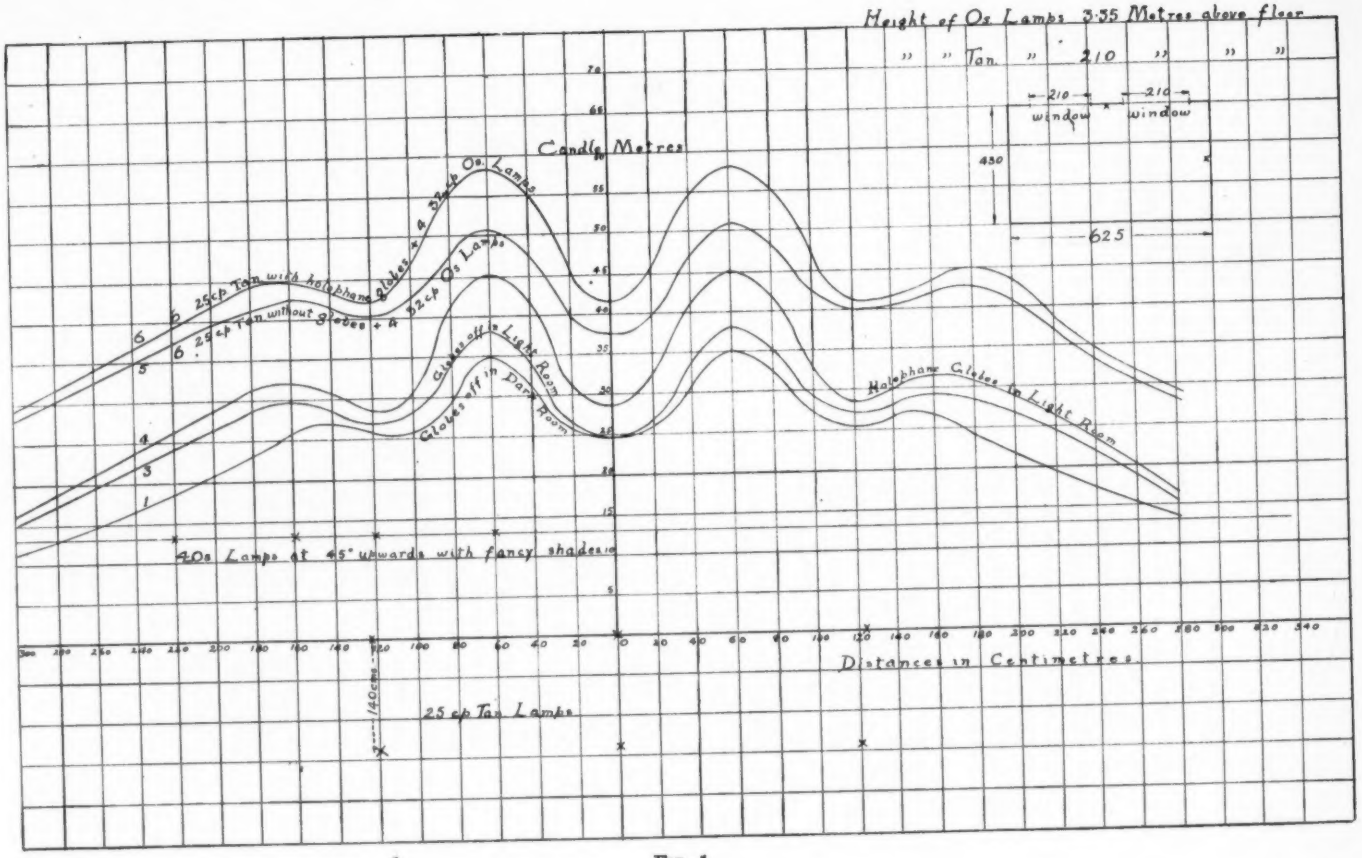

Height of Os Lamps 3·35 Metres above floor
" " Tan " 210 " " "
210 window
210 window
450
625
Candle Metres
25cp Tan with holophane Globes + 4 32cp Os Lamps
25cp Tan without Globes + 4 32cp Os Lamps
Globes off in Light Room
Globes off in Dark Room
Holophane Globes in Light Room
4 Os Lamps at 45° upwards with fancy shades
140cms
25 cp Tan Lamps
Distances in Centimetres

FIG. 1.

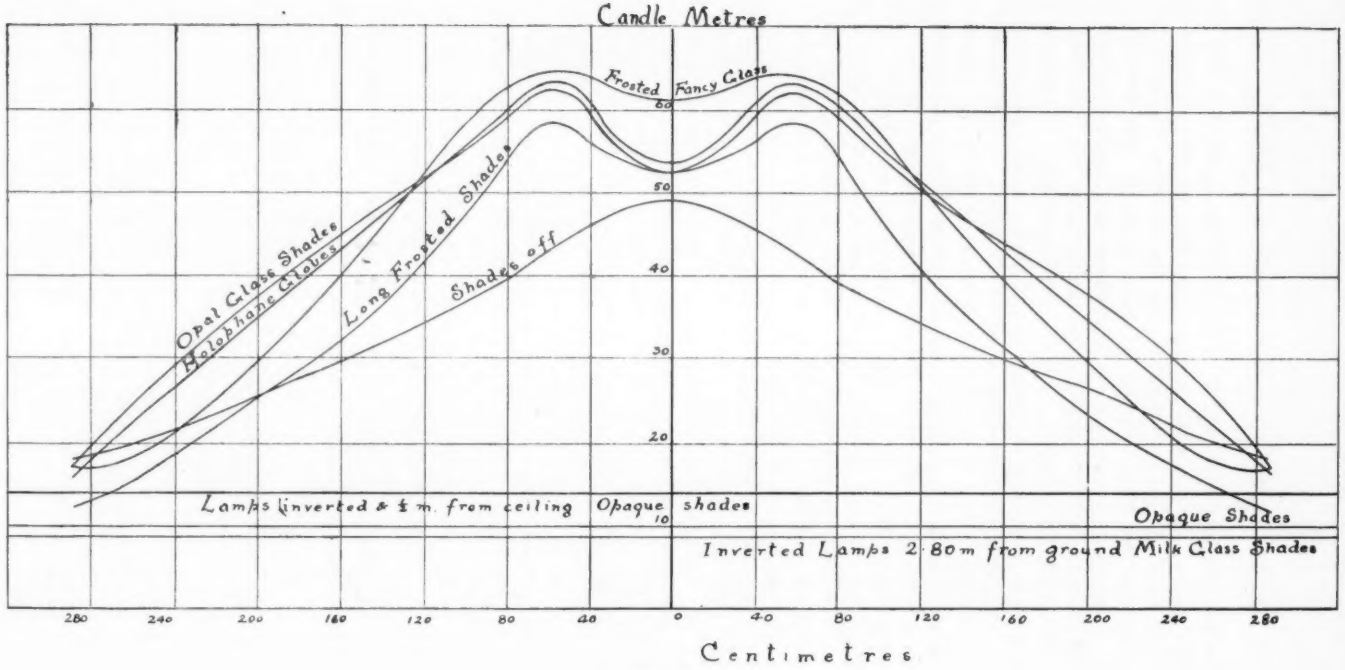

Candle Metres
Frosted Fancy Glass
Opal Glass Shades
Holophane Globes
Long Frosted Shades
Shades off
60
50
40
30
20
10
Lamps inverted & ½ m. from ceiling
Opaque shades
Opaque Shades
Inverted Lamps 2·80 m from ground Milk Glass Shades
280
240
200
160
120
80
40
0
40
80
120
160
200
240
280
Centimetres

FIG. 2.

In the dark room, on looking at the print the aperture of the pupil becomes set to a certain width as long as one does not move the eye away from the book. At the same time one has the *feeling of the surrounding blackness*, and the great contrasts prevailing make the eye roam instinctively. As soon, however, as it encounters the blackness the pupil extends. In the next instant the eye strikes again the brilliantly illuminated paper, and consequently the pupil contracts, and apparently more than is necessary, because it experienced a glare. But too much contraction makes the illumination insufficient, and so the eye has to expand again. In other words, the aperture of the pupil alternately expands and contracts, making a higher average illumination necessary.

In a room with white walls and ceiling, and especially with uniform illumination, the eye does not experience any great contrasts, and it may consequently set itself definitely to a certain aperture, which does not alter even if the eye roams about the room. A smaller illumination is thus required, because the pupil can extend to a maximum without having to be afraid of glare.

It might be added here that even the ordinary black print on white paper causes some glare, and I have no doubt that for the preservation of the eyes coloured print would be preferable.

In conclusion, I add a few curves (Fig. 2) which deal with the illuminations derived from various types of lamp shades. The superiority as regards uniformity of the prismatic glass or holophane shade is strikingly illustrated. It might be further improved by lengthening the shade or surrounding it with a deep, slightly obscuring frosted globe. The long frosted shade, although it diffuses the light badly, hides the whole lamp bulb, and the filament is therefore invisible. The intrinsic brilliancy is thereby greatly reduced.*

All the tests were carried out on a horizontal plane 1 metre above the floor, as this is now recognised as the standard test plane. Testing the illumination of inclined planes would make it impossible to take into account the illumination from all sources taking part in the lighting of the regions to be tested.

* The holophane shades are somewhat expensive. Fig. 2 shows, however, that with the ordinary conical opal shade a uniformity superior to that of holophane globes may be obtained. The lamps must, however, be hung close to the ceiling, as the shades do not obscure the lamps.

THE EFFECT OF THE ELECTRIC DISCHARGE ON WATER VAPOUR.

By E. Jacot, B.A.

(Plates II., III.)

(Communicated by W. H. Logeman, M.A.)

(Read July 20, 1910.)

Introductory.—This research was initially undertaken with a view to verifying the results set forth by M. A. Henry in the *Journal de Physique* (tome viii., Jan., 1909, pp. 33–38), namely, that a vacuum tube containing only water vapour will show Cooke's effects at considerably higher pressures than if it contained air; *i.e.*, that the upper limit of pressure suitable for the existence of cathode rays, and consequently of Röntgen rays, is much higher in the case of water vapour than in the case of air.

At an early stage of the work, however, unexpected effects occurred, and the investigation of these rendered the original subject of research altogether secondary.

Method of Procedure.—The method of procedure and the experimental arrangements were essentially different to those of M. Henry. In principle, the method first intended to be employed was the following: An ordinary X-ray bulb, fitted with suitable means for admitting various quantities of air or water vapour, was connected to a mercury pump. Air pressures were read by a McLeod gauge, and pressures of water vapour by a manometer of the ordinary kind. Exhaustion was carried on until the bulb emitted good X-rays, and the quantity of air or water vapour necessary to cause a cessation of the emission of rays was then noted.

Methods of admitting Water Vapour.—The first method of introducing water vapour into the bulb was through a fine capillary of such small bore that air could be admitted at the rate of twenty to thirty thousandths of

a millimetre per minute when exhaustion had been carried to 0·000 mm. (*i.e.*, less than $\frac{5}{10000}$ mm.). Fig. 1 is a diagrammatic sketch, showing the arrangement. The end of the capillary is surrounded by the vapour from the boiling water in the flask F; *ll* serves to break off a short length of the capillary when vapour is required to be admitted. The bulbs B_1, B_2 contain P_2O_5. Connection between these bulbs and the X-ray bulb is made through mercury traps.

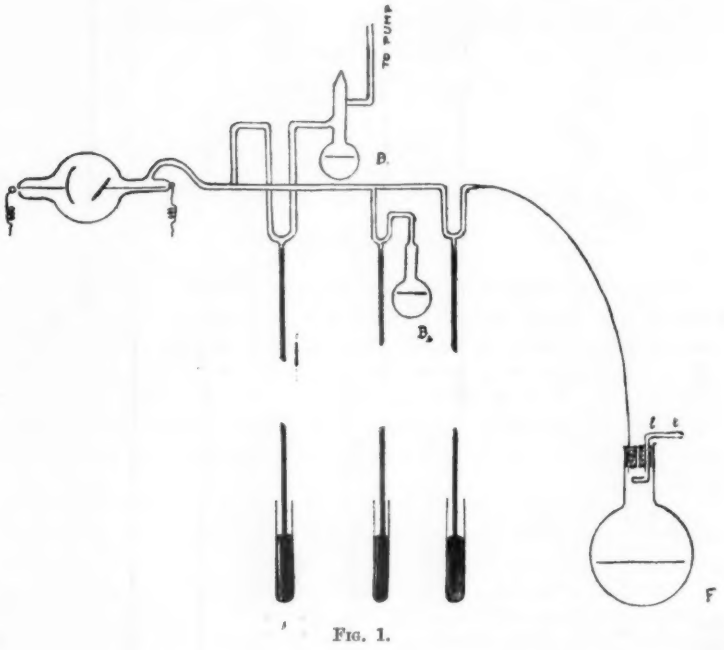


FIG. 1.

This method of introducing the vapour was found to be unsatisfactory. Some vapour or gas, unabsorbed by P_2O_5, invariably remained after the introduced water vapour had been admitted to the P_2O_5 bulbs; the McLeod gauge indicated pressures varying from a few thousandths to a few hundredths of a millimeter.

Fig. 2 illustrates the second method of introducing vapour. The bulb W contained water and water vapour only. To introduce the vapour into the X-ray bulb, &c., the mercury was made to fall below J by lowering the reservoir R. The tube *ab* was 80 cm. long. Its

dimensions were such that if at any time it was necessary to open the apparatus (*e.g.*, to change the X-ray tube) the mercury might be made to fill the tube to such a height that the pressure in the apparatus might

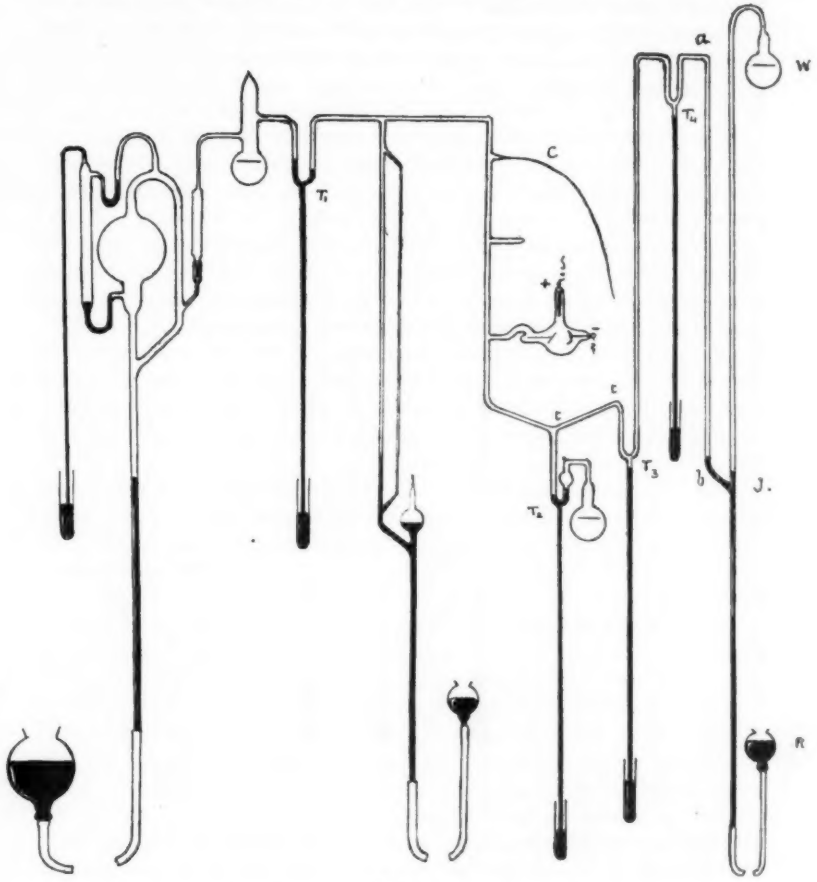


FIG. 2.

rise to one atmosphere without the mercury falling below J, so that by merely raising R sufficiently, W remained cut off and the water vapour unmixed with air.

The arrangement was connected to the remainder of the apparatus through two mercury traps separated by 80 cm. of 3-mm. bore-tubing

(see Fig. 2). The object of this was to allow of the introduction of definite small quantities of vapour into the apparatus. Vapour under various pressures ranging to saturation pressure was introduced into the exhausted apparatus and absorbed, in order to test for the presence of any unabsorbable gas carried over with the vapour. The results were satisfactory. After the first two trials the pressures indicated by the gauge after the vapour had been absorbed varied from 0·001 mm. downwards. This method of admitting vapour was adopted.

Experimental Arrangements.—Fig. 2 shows the complete apparatus as finally used. The trap T served to separate the pump and P_2O_5 bulb from the rest of the apparatus, so that the X-ray tube and the McLeod gauge might be connected without the inclusion of any P_2O_5 bulb. It also served as a manometer for measuring the pressure of vapour introduced into the X-ray tube. The capillary C was added as a means of introducing air or other gases quite independently of the introduction of water vapour. The slope of the tube *tt* was for the prevention of its obstruction by mercury carried over from the trap T_3 when this was opened for the introduction of the vapour; for at this stage the trap separated two regions of the apparatus, in one of which was a pressure of 0·000 mm., and in the other of which was saturation pressure of water vapour.

The X-ray tubes first used were of the ordinary type, with aluminium cathode and platinum anode and anticathode combined. An ordinary 10-inch spark induction coil, with platinum contact-breaker, was used for the discharge, worked by accumulators giving 8 volts. The spark-length (between points) in air was about 2·5 cm.

Experiments were first made with air. The air was admitted through the capillary, and the variation in quality of the X-rays tested by observing the sharpness and intensity of a shadow cast on a barium platino-cyanide screen. These experiments yielded no satisfactory results, the behaviour of the various tubes being very inconsistent. A characteristic inconsistency was in the reduction of pressure produced by the discharge. This phenomenon was present in most of the tubes, but it was very much more marked in some cases than in others. In one instance the discharge disposed of the air as fast as it was introduced through the capillary, so that, with the capillary broken, the tube was giving good rays for several minutes. Blackening of the tubes through the disintegration of the electrodes was rapid and considerable, more especially when the pressure of air in the tube was too high for the passage of the discharge to be attended by any fluorescence of the glass. Attempts were made to diminish this effect by varying the form of X-ray tube. The form of tube shown in Fig. 3 is that which proved to be the most successful. The anode was made in the form of a long spiral of aluminium, with the object of exposing

a large surface. The anticathode, of platinum, was not used as an electrode.

Experiments with Water Vapour.— It was found impossible to determine what pressure of vapour would cause a cessation of the emission of rays; for immediately on passing the discharge through the vapour the pressure, as indicated by the McLeod gauge, increased rapidly, showing that gas was being formed at a rapid rate, while the fluorescence of the X-ray tube ceased almost immediately.

These increases in pressure were not consistent, owing, no doubt, to variations in temperature, variations in the physical conditions in the X-ray tube, &c. In every case, however, these increases tended to a limit.

If, after gas had been formed in this way, the trap T_2 was opened, so that connection between the X-ray tube and the P_2O_5 bulb was brought about, the pressure as indicated by the gauge was found to fall at a diminishing rate as the passage of the discharge continued.

From these preliminary experiments it would appear that the effect of the discharge on small quantities of water vapour is to cause partial dissociation. A definite fraction of the vapour would become dissociated into the electrolytic gases H_2 and O_2. If the vapour, in the meantime, remained unabsorbed, this dissociation would continue till the pressure of electrolytic gas attained to a steady value. If, however, the vapour, which would still exist undissociated, were now absorbed, the pressure conditions would no longer be in equilibrium. Some of the electrolytic gas would recombine to form H_2O; but as fast as this recombination took place, the water would be absorbed by the P_2O_5, a steady state of pressure would no longer be possible, and the pressure indicated by the McLeod gauge would fall off with time.

Reduction Effect.—After the above experiments with water vapour had been conducted, it was found that immediately on introducing any water vapour, gas began to be formed, quite independently of the passage of any discharge. The pressure as indicated by the McLeod gauge increased steadily to a maximum and permanent value. This effect seems to have been due directly to some change in the internal condition of the X-ray tube brought about by the passage of the previous discharges.

The effect grew rapidly with time. Thus, five days after the discharge had been passed for the first time, on allowing vapour under saturation pressure (12 mm.) to stand in the apparatus (initially evacuated to 0·000 mm.), it was found that after 18 hours, the pressure of gas formed had attained to the order of 1 cm.

The seat of the effect was found to be in the X-ray tube; for, on removing the latter, the effect was greatly reduced. An attempt was then

made to remove the cause of the effect. The apparatus was steamed for two hours between T_1 and T_4, and fresh mercury put in the manometers and traps. On now allowing vapour under saturation pressure to stand in the apparatus, the effect was found to be enormously reduced.

Initial pressure : 0·000 mm.

VAPOUR ADMITTED (UNDER SATURATION (12 MM.) PRESSURE).

Intervals of Time.	Pressures as per Gauge.
1 min.	0·001 min.
7	0·004
14	0·005
31	0·0045
51	0·0045

The seat of this minute remaining effect was found to be in the bulb of the McLeod gauge itself. This result is natural enough; for, during the process of steaming the apparatus, the gauge bulb, which afforded no exit for the steam, could not have been subjected to so thorough a cleansing as the other parts of the apparatus. In the course of the next few days, this residual effect disappeared.

The X-ray tube, after having been thoroughly steamed, was then refitted, the previous effect tested for, and found unrenewed.

Preparatory to repeating experiments on the passage of the discharge through water vapour, the discharge was passed for some time through two or three thousandths of a millimetre of air, pumping being at the same time kept up; the object being the driving out and removal of as much as possible of the gas which might be occluded in the walls of the tube and in the electrodes.

After this had been satisfactorily done, it was found that on allowing water vapour under its saturation pressure to stand in the apparatus, the pressure as indicated by the gauge began to increase steadily. The discharge, at the time, was not being passed. The previous effect, then, was once more present, and must have been brought about solely by the last passage of the discharge. On repeating the experiment, the effect increased in magnitude; and very shortly afterwards, on allowing vapour under its saturation pressure to stand in the apparatus, the pressure of gas formed after 15 hours, reached a value of the order of $1\frac{1}{2}$ cm. At the same time, the cathode had become incrusted with a greyish growth. Enough gas had been formed to allow of its being pumped out and

collected. About 3 cc. were collected over mercury and found to be inflammable.

These results seem to point to a reduction of the water vapour, probably by aluminium-mercury-couple, formed from the aluminium in the presence of mercury, or perhaps even of mercury vapour, hydrogen being liberated and the aluminium being converted into the hydrate AlO_3H_3. This reduction, however, apparently cannot take place unless the discharge has passed at least once through the tube; but once it has been brought about, it increases rapidly in magnitude.

Experiments were made which showed that the presence of aluminium in contact with mercury vapour was solely responsible for the supposed reduction effect on the water vapour, but that the passage of a discharge at least once was always necessary before the effect occurred. Water vapour suffered no reduction if admitted into a new tube. A point of some interest noted in the course of these experiments was that the aluminium in the tube need not necessarily form one of the electrodes; indeed it might even be quite removed from the direct path of the discharge.

Elimination of the Reduction Effect.—With a view to eliminating the reduction effect, a discharge tube containing no aluminium, about 13 cm. long, with two platinum wire electrodes, was fitted.

Vapour under its saturation pressure was allowed to stand in the apparatus on three successive occasions, and any reduction effect found to be totally absent.

On passing the discharge through vapour under 0·9 mm. pressure, the tube being free of any platinum-black, the McLeod gauge indicated a small increase in pressure from 0·015 mm. to 0·017 mm. (Curve 1.)

On repeating the experiment the results were as follows:—

Initial pressure: 0·000 mm.

11.27 A.M. SAME QUANTITY H_2O ADMITTED, AND DISCHARGE PASSED CONTINUOUSLY.

Time.	Pressure as per Gauge.
11.32 a.m.	0·047 mm.
11.39	0·030
11.46	0·020
11·54	0·021

(Curve 2.)

During the latter part of the experiment the cathode was at a red heat, and intense disintegration was taking place. The tube, in the neighbourhood of the electrodes, more especially the cathode, was now very black.

The above experiments were repeated, with the tube in the same condition, on three occasions when the temperature conditions were much the same. Curve 3 shows how the pressure as indicated by the McLeod gauge varied with time on each occasion. The pressure increased rapidly during the first few minutes to a maximum value, after which it fell at a diminishing rate. Curve 4 shows a case where the P_2O_5 bulb was put into connection with the remainder of the apparatus immediately after this maximum value of the pressure had been attained. It serves to compare the action of the P_2O_5 with that of the agency responsible in these last experiments for the falling off of the pressure with time.

This agency must be the platinum-black on the walls of the tube; for the falling off of pressure with time was absent when the tube was clean, and increased simultaneously with the formation of the deposit. That the seat of the effect was actually in the discharge tube was verified experimentally.

Experiments with the Electrodeless Discharge.—In order to remove the effect apparently due to the platinum-black, a tube with no electrodes was substituted for the last discharge tube. The tube, 15 cm. in length, was made of 1·5 cm.-bore soda-glass tubing. The ends were knob-shaped and covered with tinfoil caps to which were connected the wires from the induction coil.

The gases from the walls of the tube were driven out and removed by pumping at intervals while the discharge was passed through air under a pressure of a few thousandths of a mm. Hg. During this process a belt of brownish-black coloration appeared near the cathode extremity of the tube. The discharge was passed through vapour under 0·9 mm. pressure on three successive occasions, the temperature conditions being very similar (about 14° C.). Curve 5 shows how the pressure as registered by the McLeod gauge varied with the time on each occasion. During the first few minutes there was a rapid increase to 0·08 mm., after which there was a falling off at a diminishing rate. The results are very similar to those obtained when corresponding experiments were conducted with the previous tube. The coloration on the walls of the tube remained throughout the experiments.

The discharge was passed through vapour under 1·7 mm. pressure, the temperature being 14·5° C. As before, the pressure increased to a maximum, and then decreased at a diminishing rate; but the

maximum in this case was greater while the decrease in the pressure was less. (Curve 6.)

As the pressure of gas produced approached its maximum value the coloration on the tube began to disappear; at the end of the experiment, however, the greater portion was still present.

The discharge was passed through vapour under 2·6 mm pressure, the temperature being 14·5° C. The pressure again immediately began to increase, while the coloration, from the instant of starting the discharge, disappeared rapidly. When the pressure as indicated by the gauge had reached the value 0·308 mm., the last traces of colour had vanished. After this point the pressure did not vary much. (Curve 7.) Three and a half hours afterwards (the discharge having passed continuously) the pressure as indicated by the gauge was 0·307 mm., while the tube had remained perfectly free of coloration. In this case, then, we have again a rise in pressure to a maximum value; but the maximum is permanent; there is no subsequent falling off of the pressure.

The tube being now free of coloration, the above experiments were repeated:

The discharge was passed through vapour under 0·9 mm. pressure, (temperature = 14° C.). The pressure increased to a maximum value 0·07 mm., after which it did not appreciably diminish. Until the maximum had been reached, the tube remained perfectly free of coloration. After this faint traces of returning coloration began to appear. (Curve 8.)

The discharge was passed through the same quantity of vapour. The coloration became more apparent, and the pressure increased to a higher maximum than before, after which it diminished for a short time. (Curve 9.)

The discharge was passed through vapour under a pressure of 2·7 mm. As in the previous parallel case, the coloration immediately began to vanish, while the pressure as indicated by the gauge rose to a maximum and permanent value of 0·34 mm., when the last traces of coloration disappeared.

The coloration, then, occurred if the pressure under which vapour was admitted was less than about 2·5 mm. If the coloration was present and the discharge was passed through vapour under a pressure just greater than 2·5 mm., the coloration disappeared, while the pressure of gas in the apparatus increased to a permanent maximum value. Further, as the following results show, if the discharge is passed through the same quantity of vapour, while the tube was free of colour, the pressure, as before, increased to a permanent maximum value, while there was at no time any coloration.

Tube free of colour.

Temperature 14·3° C.

DISCHARGE PASSED THROUGH VAPOUR UNDER PRESSURE OF 2·6 MM.

Intervals of Time.	Pressure as per Gauge.
1 min.	0·037 mm.
3	0·175
6	0·234
9	0·289
13	0·325
18	0·339
21	0·338
40	0·339

Discharge stopped.

Tube free of colour.

It appears reasonable to suppose that this coloration was the result of chemical action of cathode rays on the glass. According to J. J. Thomson ("Conduction of Electricity through Gases," 2nd edition, p. 623) such coloration rapidly disappears on mere exposure to water vapour. In the present instance, however, the passage of a discharge through the water vapour was found to be essential for the vanishing of the coloration; *e.g.*, the pressure of gas in the apparatus being initially 0·000 mm., vapour under its saturation pressure (12 mm.) was admitted and allowed to stand for twenty hours. At the end of this time there was no apparent diminution in the coloration, while the McLeod gauge indicated a pressure of gas of 0·001 mm., showing that no appreciable dissociation or reduction of the vapour had taken place. On passing the discharge, however, a considerable amount of the coloration had already disappeared at the end of two minutes and was fast continuing to do so.

On passing the discharge through vapour under pressures greater than about 2·5 mm., the pressure corresponding to unstability of the coloration, the gauge readings indicated increases in pressure to permanent maximum values. (Curves 10, 11, 12, 13, 14.) These maximum values did not become continually greater as the pressure of vapour admitted became greater. They differed little from one another except when the pressure of vapour admitted approached saturation pressure (11 to 12 mm.).

Thus :—

Pressure under which Vapour was admitted.	Maximum Pressure of Gas produced.
2·6 mm.	0·340 mm.
4·0	0·306
7·1	0·354
8·0	0·41
8·8	0·44
10·0	1·08
12·0 (Sat. press.)	2·85

The time taken for the pressures to attain to their maximum values increased as the pressure under which the vapour was admitted became greater—a result to be expected, for the more water vapour is initially introduced the greater will be the hindrance to diffusion of the gas produced through the apparatus, and, consequently, the longer will be the time for a state of equilibrium to be set up. The temperature during these observations was in the neighbourhood of 14° C., but not particularly constant.

A series of experiments was made to determine how these maximum pressures, in addition to depending on the pressure under which the vapour stood initially in the apparatus, depended on the temperature. These experiments were conducted with a new tube, similar in construction to the last, although differing slightly in its dimensions. The renewal of the tube was necessary owing to the breaking down of the previous one, due, presumably, to its perforation by the discharge. The gases from the walls of the tube were driven out as before; and, as before, a belt of colour again formed near the centre of the tube during the process. Experiments identical with those conducted with the previous tube were made, and served to confirm the previous results. The maximum pressure of gas formed increased with the pressure under which vapour was introduced, up to the point of disappearance of the coloration. In this case, however, it was necessary to pass the discharge through vapour under 4 mm. pressure before the last traces of colour completely vanished. Also, as before, when the pressure under which the vapour was admitted was less than 4 mm., the pressure of gas formed, after reaching its maximum value, diminished at a decreasing rate; *i.e.*, provided some coloration was present, the maximum pressures of gas formed was followed by a diminution at a decreasing rate. Curves 15, 16, 17, 18, 19, 20 show how the pressure of gas formed by the passage of the discharge varied with the time, when the discharge was passed through vapour under various pressures up to 4 mm.

The discharge was passed through vapour under various pressures, ranging to saturation pressure, for certain temperatures, the method of procedure being as follows: After exhausting the apparatus included between the traps T_1 and J to 0·000 mm., the requisite amount of vapour was introduced, and trap T_4 closed to separate the discharge tube, McLeod gauge, &c., from any moisture that might rise to the surface of the mercury at *b* during the course of the experiment. At the end of each experiment, immediately after the discharge had been stopped, the water vapour was absorbed, and the apparatus again exhausted to prevent any appreciable occlusion of gas in the walls of the tube, which would be driven out by the discharge in the next experiment, and so cause error. In order to maintain the temperature constant the days were chosen cooler by two or three degrees than the required temperature, and the temperature kept up by regulating a number of glow-lamps. In this way it was found possible to prevent the temperature from varying by more than 0·1° C.

Following is a series of experiments conducted at the temperature 19·8° C. The series is typical of others:—

(1) At 1.0 p.m. Discharge passed through H_2O under 0·6 mm. Pressure.

Times.	Pressures.	Temperature.	Remarks.
1.1 p.m.	0·050 mm.	19·80° C.	Faint green fluorescence.
1.3	0·060	19·80	—
1.5	0·055	19·80	Appearance of coloration.
1.10	0·047	19·80	—
1.14	0·041	19·80	—
1.36	0·036	19·80	Signs of more pronounced fluorescence.

(2) At 3.19 p.m. Discharge passed through H_2O under 2·1 mm. Pressure.

Times.	Pressures.	Temperature.	Remarks.
3.21 p.m.	0·095 mm.	19·80° C.	Very narrow striations with faint fluorescence.
3.26	0·196	19·85	—
3.29	0·217	19·85	—
3.32	0·220	19 85	Striations less distinct.
3.40	0·219	19·85	—
3.52	0·217	19·80	—
4.2	0·213	19·80	—
4.11	0·208	19·80	Coloration still present.

(3) At 4.20 p.m. Discharge passed through H_2O under 3·5 mm. Pressure.

Times.	Pressures.	Temperature.	Remarks.
4.30 p.m.	0·243 mm.	19·85° C.	No distinct striations.
4.40	0·290	19·85	Coloration began to disappear immediately. At 4.40 only a faint trace remained.
4.50	0·301	19·85	
4.59	0·310	19·80	
5.14	0·306	19·80	Last trace of coloration disappeared.

(4) At 2.3. p.m. Discharge passed through H_2O under 3·7 mm. Pressure.

Times.	Pressures.	Temperature.	Remarks.
2.6 p.m.	0·091 mm.	19·85° C.	—
2.12	0·221	19·80	—
2.22	0·282	19·75	—
2.34	0·302	19·80	—
2.42	0·301	19·85	No return of coloration at any time.

(5) At 2.55 a.m. Discharge passed through H_2O under 4·9 Pressure.

Times.	Pressures.	Temperature.
3.6 p.m.	0·215 mm.	19·80° C.
3.11	0·256	19·80
3.17	0·274	19·80
3.27	0·283	19·80
3.34	0·282	19·80

(6) At 11.30 A.M. Discharge passed through H_2O under 5 mm. Pressure.

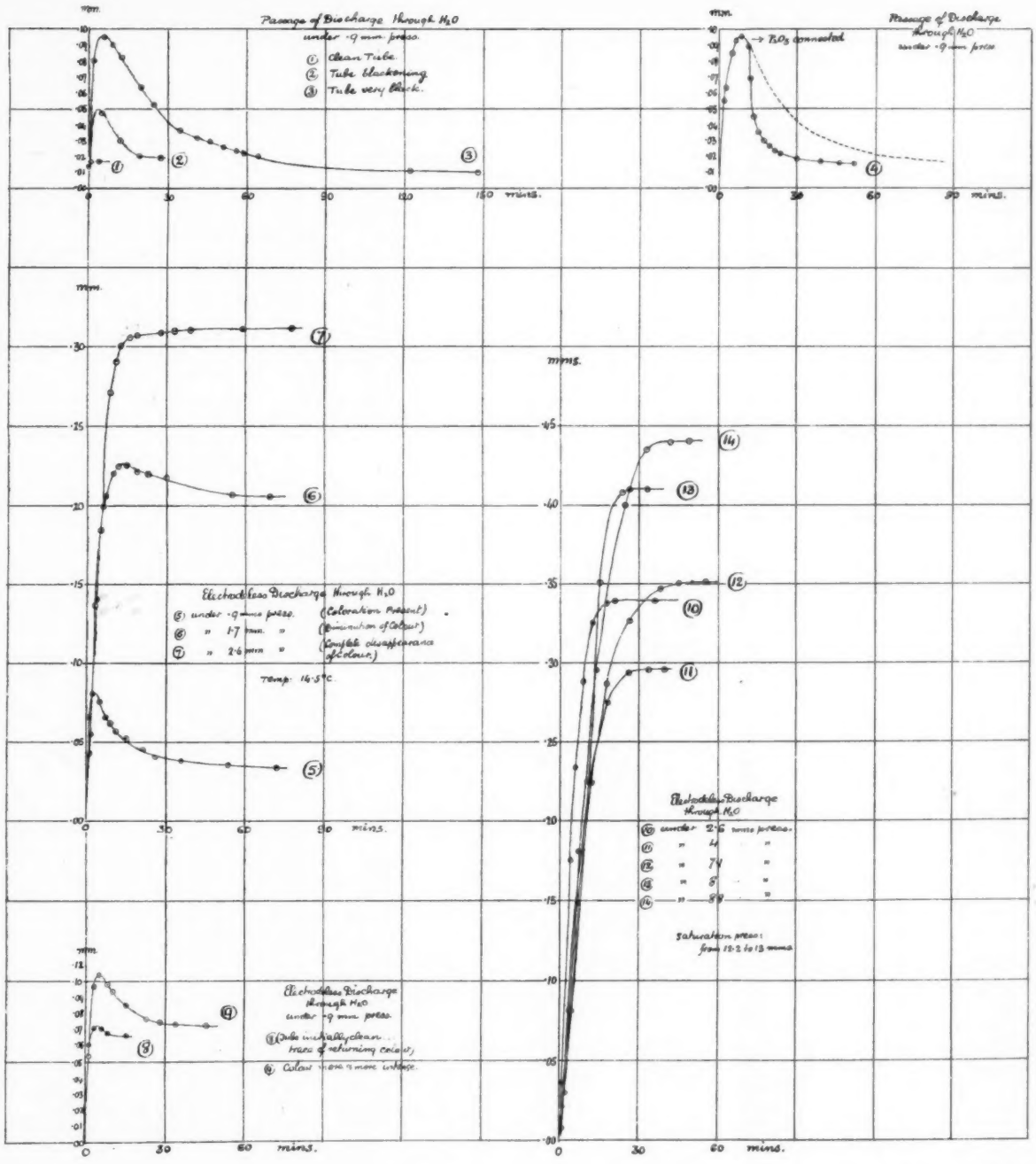
Times.	Pressures.	Temperature.
11.42 a.m.	0·188 mm.	19·70° C.
11.49	0·228	19·80
11.58	0·243	19·85
12.8 noon	0·253	19·85
12.23	0·256	19·75
12.32	0·263	19·70
12.56	0·279	19·75
1.0 p.m.	0·279	19·80

(7) At 3.46 P.M. Discharge passed through H_2O under 6·2 mm. Pressure.

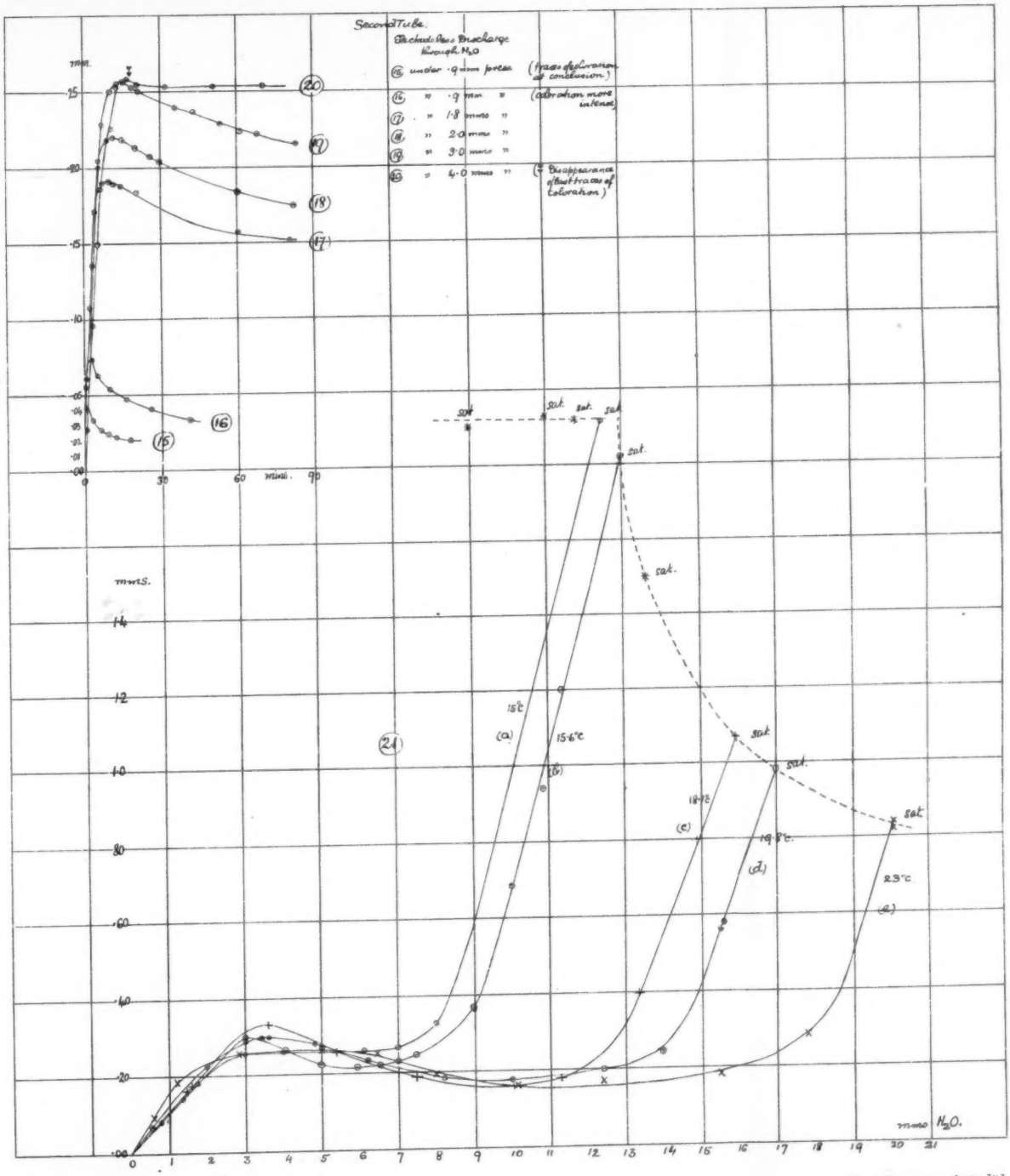
Times.	Pressures.	Temperature.
3.59 p.m.	0·184 mm.	19·70° C.
4.11	0·227	19·85
4.22	0·228	19·80
4.28	0·227	19·80

(8) At 2.6 P.M. Discharge passed through H_2O under 8·3 mm. Pressure.

Times.	Pressures.	Temperature.
2.13 p.m.	0·079 mm.	19·80° C.
2.17	0·112	19·80
2.31	0·168	19·80
2.47	0·182	19·85
3.4	0·188	19·85
3.10	0·188	19·85


Passage of Discharge through H_2O under ·9 mm press.
① Clean Tube.
② Tube blackening
③ Tube very black.
mm.
mins.
Passage of Discharge through H_2O under ·9 mm press
→ TiO_2 connected
Electrodeless Discharge through H_2O
⑤ under ·9 mm press. (Coloration present)
⑥ " 1·7 mm. " (Diminution of Colour)
⑦ " 2·6 mm " (Complete disappearance of colour)
Temp. 14·5°C.
Electrodeless Discharge through H_2O under ·9 mm press.
⑧ (Tube initially clean ... trace of returning colour)
⑨ Colour more & more intense.
Electrodeless Discharge through H_2O
⑩ under 2·6 mms press.
⑪ " 4 "
⑫ " 7·4 "
⑬ " 8 "
⑭ " 8·8 "
Saturation press: from 12·2 to 13 mms

West, Newman photo-lith.



West, Newman photo-lith.

(9) At 4.35 p.m. Discharge passed through H_2O under 10 mm. Pressure.

Times.	Pressure.	Temperature.
4.42 p.m.	0·070 mm.	19·75° C.
4.46	0·101	19·80
4.48	0·112	19·80
4.53	0·135	19·80
4.56	0·145	19·80
5.21	0·174	19·80
6.5	0·179	19·70

(10) At 9.35 a.m. Discharge passed through H_2O under 12·4 mm. Pressure.

Times.	Pressure.	Temperature.
9.36 a.m.	0·007	19·80° C.
9.38	0·030	19·80
9.40	0·060	19·80
9.43	0·099	19·80
9.45	0·119	19·80
9.51	0·162	19·85
9.56	0·185	19·85
10.3	0·200	19·85
10.16	0·202	19·85
10.20	0·202	19·85
10.27	0·202	19·80

(11) At 3.26 p.m. Discharge passed through H_2O under 14 mm. pressure.

Times.	Pressure.	Temperature.
3.41 p.m.	0·158 mm.	19·80° C.
3.45	0·195	19·80
3.57	0·244	19·80
3.67	0·256	19·80
4.20	0·255	19·85

(12) At 2.3 p.m. Discharge passed through H_2O under 15·5 mm. Pressure.

Times.	Pressure.	Temperature.
2.5 p.m.	0·010 mm.	19·85° C.
2.8	0·045	19·75
2.18	0·026	19·75
2.27	0·35	19·80
2.45	0·48	19·80
2.57	0·53	19·80
3.8	0·56	19·85
3.18	0·56	19·80

(13) At 4.57 p.m. Discharge passed through H_2O under 15·6 mm. Pressure.

Times.	Pressure.	Temperature.
5.0 p.m.	0·022 mm.	19·90° C.
5.2	0·060	19·90
5.6	0·122	19·90
5.10	0·230	19·90
5.13	0·285	19·80
5.21	0·580	19·75

(14) At 10.43 a.m. Discharge passed through H_2O under 16 mm. Pressure.

Times.	Pressure.	Temperature.
10.46 a.m.	0·022 mm.	19 85° C.
11.7	0·49	19·75
11.17	0·60	19·80
11.26	0·66	19·85
11.35	0·70	19·85
11.41	0·71	19·80

(15) DISCHARGE PASSED THROUGH H_2O UNDER 17 MM. (SATURATION) PRESSURE (TRAP T_4 BEING OPEN, AND MERCURY AT *b* JUST WET.)

Times.	Pressure.	Temperature.
12.5 noon.	0·000 mm.	19·80° C.
12.6	0·002	19·80
12.10	0·081	19·85
12.24	0·40	19·80
1.27	0·98	19·80
1.37	0·98	19·80

Curve 21(*d*) shows how the maximum pressure due to electrolytic gas produced by the passage of the discharge varied with the pressure under which the water vapour was admitted into the apparatus. Up to that critical value of the pressure under which the vapour was admitted, at which the passage of the discharge brought about the disappearance of the coloration, the maximum pressure due to gas increased with increasing pressure under which vapour was admitted. At the critical value referred to there was a turning-point, and the pressure due to gas fell slightly for a certain range of water-vapour pressures, till a second critical value of the latter quantity was reached. Beyond this point the maximum pressure due to electrolytic gas increased rapidly and linearly with the pressure under which vapour was admitted, till this quantity reached the value of "saturation pressure."

Curves 21 (*a*) (*b*) (*c*) (*e*) show how the maximum pressure due to electrolytic gas varied with the pressure under which water vapour was admitted for temperatures of 15° C., 15·6° C., 18·7° C., and 23° C. respectively. Their general nature is similar to that for 19·8° C., except in the case of 21(*a*), in which the portion of the curve between the two critical points is horizontal.

The gradients of the curves near the origin increase with increase of temperature. The gradients of the curves beyond the second critical point appear to be independent of the temperature.

The maximum pressure of gas formed by the passage of the discharge through vapour under saturation pressure diminished as the value of the saturation pressure increased, and appeared to do so according to a well-defined law. This variation was investigated. The discharge was passed through vapour under saturation pressure at other temperatures on several occasions. The final pressures of gas formed in various instances are shown in 21. From the results obtained it seems that the pressure of gas produced was almost independent of the value of the saturation pressure,

and hence independent of the temperature, for values of the temperatures less than about 15° C., while it decreased with increase of temperature for values greater than 15° C., as shown by the dotted curve in Fig. 21.

Summary.

1. Water vapour is unstable in the presence of aluminium and mercury vapour in a vacuum tube through which the electric discharge has been passed. Reduction of the vapour, probably by mercury-aluminium-couple appears to take place.

Though the experiments made by M. Henry were essentially different to those of the writer, the tubes used by M. Henry were fitted with aluminium electrodes and a mercury manometer. It seems difficult, therefore, to reconcile the results obtained by the writer with those of M. Henry, since it would appear that any vapour admitted would suffer reduction; hydrogen would be liberated, and the pressure of gas in the tube would continually increase so long as the vapour remained unabsorbed in the tube.

2. No such reduction takes place on allowing water vapour to stand in a tube fitted with platinum electrodes only, and containing no aluminium. If the discharge is passed through the vapour, there is a rise in pressure, indicating the formation of some gas or gases—a result possibly due to partial dissociation of the vapour by the discharge. When the electrodes have suffered some disintegration, so that there is a deposit of platinum-black on the walls of the tube, the pressure of gas formed does not rise to a permanent value; it passes through a maximum after a few minutes, and then falls off with time at a diminishing rate.

3. The passage of the discharge through water vapour under pressures of the order of 1 mm. in an electrodeless tube brings about the appearance of a brownish-black coloration on the walls of the tube—a result probably due to chemical action of cathode rays on the glass. The coloration acts somewhat similarly to the platinum-black in the previous case. The discharge again causes a rapid formation of gas. There is a rapid rise in pressure to a maximum value, after which the pressure falls off at a diminishing rate. The value of this maximum pressure of gas increases as the pressure under which water vapour is admitted increases, till this quantity attains to a definite critical value. In vapour under this pressure the coloration is no longer stable. The passage of the discharge through vapour under such a pressure causes a rapid disappearance of the colour, and the higher the pressure under which vapour is admitted the more rapid is the disappearance.

Mere exposure to moisture causes no appreciable diminution in the intensity of the coloration.

As the pressure under which the vapour is admitted approaches the critical value for which the coloration is unstable when the discharge is passed, the falling off of the pressure of gas after the maximum has been reached diminishes. With the disappearance of the last traces of colour the falling off ceases altogether. The passage of the discharge through vapour under pressures greater than the critical pressure causes a rapid increase in the pressure of gas formed, but the pressure does not pass through a maximum; its highest value is a permanent value. These highest values do not vary greatly until the pressure under which the vapour is admitted approaches saturation pressure. But the time taken to reach these highest values increases as the pressure under which the vapour is admitted becomes greater. When this last approaches saturation pressure, these highest values begin to increase rapidly and linearly with the pressure under which the vapour is admitted, until this quantity attains to the value of saturation pressure.

The value of the maximum pressure of gas formed when the discharge is passed through vapour under saturation pressure, appears to be independent of the value of the saturation pressure, up to a definite critical value of this quantity. For values greater than this critical value, the maximum pressure of gas formed decreases as the saturation pressure increases.

The writer's thanks are due to Mr. W. H. Logeman, M.A., for his help and suggestions in the course of the research.

THE ABSORPTION-SPECTRUM OF OXYGEN AND A NEW LAW OF SPECTRA.

By James Moir, D.Sc., M.A., F.R.S.S.Afr.

(Read May 18, 1910.)

The remarkable multiplex bands known as the A, B, and α lines of the solar spectrum are known to be due to absorption of the sun's light by the oxygen of the earth's atmosphere, and in spite of their obviously rhythmic structure, have not yet been reduced to an algebraical formula as regards their wave-lengths. This the author has succeeded in doing, but the formulæ are of a new type, quite different from those of Balmer, Kayser and Runge, and Rydberg (which are functions of n^{-2}, whereas the author's formulæ depend on n^{+2}, in both cases n standing for the successive whole numbers). From the following tables it will be seen that the agreement between calculation and observation is excellent.

"Head" of A line.—This consists of a tangled pair-system starting from two slightly different fundamentals of oscillation-frequency (*in vacuo*) 13164·7 and 13163·9; the subsidiary lines differ by $0{\cdot}175n^2$ and $0{\cdot}184n^2$ respectively.

Value of n	First Members of Pairs. Frequency Calculated from $13164{\cdot}7-0{\cdot}175n^2$.	Frequency Observed (*in vacuo*).	Error.	Value of n.	Second Members of Pairs. Frequency Calculated from $13163{\cdot}9-0{\cdot}184n^2$.	Frequency Observed (*in vacuo*).	Error.
0	13164·7	13164·6 (double)	0				
1	13164·5			1	13163·7	13163·6 (double)	+ 0·1
2	13164·0	13163·5	+ 0·5 ?	2	13163·2		− 0·3 ?
3	13163·1	13162·5 ?	+ 0·6 ?	3	13162·3	13162·4	− 0·1
4	13161·9	13161·4 ?	+ 0·5 ?	4	13161·0	13161·2	− 0·2
5	13160·3	13160·0	+ 0·3 ?	5	13159·3	13159·5	− 0·2
6	13158·4	13158·2	+ 0·2	6	13157·3	13157·4	− 0·1
7	13156·1	13156·0	0 ?	7	13154·9	13155·0	− 0·1
8	13153·5	13153·5	0	8	13152·1	13152·2	− 0·1
9	13150·5	13150·6	− 0·1	9	13149·0	13149·0	0
10	13147·2	13147·3	− 0·1	10	13145·5	13145·5	0
11	13143·5	13143·7	− 0·2	11	13141·6	13141·6	0
12	13139·5	13139·7	− 0·2	12	13137·4	13137·3	+ 0·1 ?
13	13135·1	13135·3	− 0·2	13	13132·8	13132·7	+ 0·1
14	13130·4	13130·6	− 0·2	14	13127·8	13127·7	+ 0·1
15	13125·4	13125·5	− 0·1				

The observations of the closer pairs near the fundamental are somewhat defective. After the 15th pair there comes a break, and then the "tail" of A commences, again consisting of pairs. The author has suc-

ceeded in explaining this " tail " in terms of two fundamentals lying close to those of the head.

" *Tail" of A line.*—

Value of n.	First Members of Pairs.		Value of n.	Second Members of Pairs.	
	Frequency Calculated from $13167{\cdot}1-0{\cdot}1845(n+16)^2$.	Error.		Frequency Calculated from $13164{\cdot}6-0{\cdot}1833(n+15)^2$.	Error.
1	13113·8	+ 0·1	1	13117·7	+ 0·1
2	13107·3	− 0·1	2	13111·6	+ 0·1
3	13100·5	− 0·3 ?	3	13105·2	+ 0·1
4	13093·3	− 0·2 ?	4	13098·4	+ 0·1
5	13085·75	− 0·25 ?	5	13091·3	+ 0·1
6	13077·8	− 0·2 ?	6	13083·7	0
7	13069·5	− 0·2 ?	7	13075·9	0
8	13060·8	− 0·1 ?	8	13067·6	0
9	13051·8	− 0·1	9	13059·0	0
10	13042·4	0	10	13050·0	0
11	13032·6	0	11	13040·7	0
12	13022·5	0	12	13031·0	+ 0·1
13	13011·95	0	13	13020·9	+ 0·1
14	13001·05	0	14	13010·4	− 0·1 ?
15	12989·8	+ 0·1 ?	15	12999·6	− 0·1 ?
16	12978·2	+ 0·1 ?	16	12988·4	− 0·1 ?
17	12966·4	+ 0·1 ?	17	12976·8	− 0·1 ?

By these formulæ the whole of the observed lines in the A complex are accounted for, except one isolated line at 13124·6, which is possibly not a true oxygen line.

The B complex is a very close imitation of A, and consequently the formulæ required only differ as regards the constants.

Head of B.—The more accurate formulæ are—

$$\left\{\begin{matrix}14555{\cdot}5\\14557{\cdot}7\end{matrix}\right\} - 0{\cdot}26n^2 + 0{\cdot}11n,$$

which give all the lines with a maximum error of $\pm$ 0·15; but the simpler formula given in the following table is almost as accurate, and is strictly analogous to that of the A line :—

Value of n.	Frequency Calculated from $14555{\cdot}7-\frac{1}{4}n^2$.	Error Compared with Observed Values.	Value of n.	Frequency Calculated from $14557{\cdot}7-\frac{1}{4}n^2$.	Error Compared with Observed Values.
1	14555·5	0	1	14557·5	0
2	14554·7	0	2	14556·7	− 0·1
3	14553·5	0	3	14555·5	0
4	14551·7	0	4	14553·7	− 0·3 ?
5	14549·5	− 0·1	5	14551·5	− 0·2
6	14546·7	− 0·2	6	14548·7	− 0·2
7	14543·5	− 0·1	7	14545·5	− 0·1
8	14539·7	− 0·1	8	14541·7	− 0·1
9	14535·5	0	9	14537·5	+ 0·1
10	14530·7	+ 0·1	10	14532·7	+ 0·2

In the same way the tail of B is given by the formulæ—

$$14559{\cdot}6 \pm 1 - \tfrac{1}{4}(n + 12)^2.$$

"*Tail*" *of B.*—

Value of n.	Frequency Calculated from $14560{\cdot}6-\left(\frac{n+12}{2}\right)^2$.	Error.	Value of n.	Frequency Calculated from $14558{\cdot}6-\left(\frac{n+12}{2}\right)^2$.	Error.
			0	14522·6	+ 0·2
1	14518·4	+ 0·1	1	14516·4	+ 0·2
2	14511·6	0	2	14509·6	0
3	14504·4	0	3	14502·4	0
4	14496·6	0	4	14494·6	− 0·1
5	14488·4	0	5	14486·4	− 0·1
6	14479·6	− 0·1	6	14477·6	− 0·2
7	14470·4	0	7	14468·4	− 0·2
8	14460·6	− 0·1	8	14458·6	− 0·2
9	14450·4	0	9	14448·4	− 0·1
10	14439·6	+ 0·1	10	14437·6	− 0·1
11	14428·4	+ 0·2	11	14426·4	0
12	14416·6	+ 0·2	12	14414·6	0

In the B series there is again one observed line unaccounted for, viz., that at 14556·1; it has probably been wrongly observed.

The *a* complex has been too little observed to work its formula out, but it is of the same type, with a head commencing at 15923·6 (double), and a pair series beginning at 15915·8 and continuing (after a break) at 15894·9.

The author has also found a connexion between the constants of A and B: the ratio ($= \phi$) of the fundamental oscillation-frequencies is 1·10586 for both pairs; and the cube of this is the ratio of the coefficients of n^2, viz., 0·25 ÷ 0·175.

This investigation shows that the vibrations of O_2 are due to one system only, and that that system is very slightly unsymmetrical (to account for the pairs). Probably one oxygen atom has a few more electrons attached to it than the other has.

METEOROLOGY OF SOUTH AFRICA. AN INVESTIGATION INTO THE LAND AND SEA BREEZES CONDITIONS AT PORT ELIZABETH.

By A. G. Howard, M.S.A.

(Communicated by L. Péringuey, F.R.S.S.Afr.)

(Read Oct. 19, 1910.)

(Plate IV.)

The object of this paper is preliminary, as it is merely the outcome of an investigation of the 8 a.m. and 8 p.m. directions of wind at Port Elizabeth during the four years 1876 to 1879 inclusive. The facts it proves being merely deduced from two observations per day may or may not be borne out when an investigation is made having data from self-recording instruments, but enough has been elucidated to show that the results of the four years tabulations go to prove that all winds at Port Elizabeth were more or less governed by a diurnal influence analogous to land and sea breezes.

That land and sea breezes are experienced along all coasts in the world is admitted; the reasons why they should exist have also been established, so nothing need be stated here in this connection other than the effect of these conditions in South Africa.

Sometimes disturbances break into the sequences of these breezes, but an investigation of wind directions at morning and evening, extending over long periods, can always bring their existence to light.

Sometimes they are masked to a certain extent by prevailing winds, which is often the case with South Africa, but even here a careful analysis will disclose their presence.

Port Elizabeth has been chosen as a station for investigation as it is one on the high-pressure "col" between two permanent high-pressure areas, and its prevailing winds are west and east; the observer there has always been reliable, and his observations are continuous, and were made at 8 a.m. and 8 p.m.

It is well known that as the earth revolves the sun progresses *vertically* from east to west, and that a heat wave follows, having diurnal maxima and minima. But there is this difference, namely, whereas the atmosphere over the sea follows the movement of the sun and arrives at its maximum at or soon after the solar noon, that over the land attains to its

maximum much later, this lag being governed by the nature of the land surface, being later over sandy plains and earlier over forests.

It will thus be seen that there is a constant state of instability between the air over the sea and that over the land. At sunrise the air above the land has cooled much below that over the sea, and the tendency is for the prevailing wind to shift a point or two so as to blow more seawards. As the day advances the temperature of the air in general increases, and at the solar noon the maximum is reached over the sea. By this time the air temperature over the land and sea are on an equal footing. After the solar noon, however, unstable conditions set in again ; the air temperature over the sea begins to fall, but that over the land continues to rise, and in due course the prevailing wind shifts so as to blow more shorewards than in the morning.

These are the broad lines of argument to apply to any investigation of this kind.

The present investigation was the result of pure accident on the part of the author. He was about to ascertain the mean direction of wind at various stations in South Africa, and for this purpose utilised the Reports of the Meteorological Commission for 1876 to 1879 inclusive. Of all the Reports of the Commission these are the only four which give bi-daily observations of wind directions, and these had to suffice, for the present at any rate.

Port Elizabeth was the first station dealt with, and it was soon seen that some winds blew more persistently of a morning than of an evening, while the reverse was the case with others. This brought up the thought of land and sea breezes, so the original object was abandoned for a time, and the present paper was the result.

In dealing with this question the wind rose has been divided into eight points: north winds include those from the NNW. and NNE.; west winds those from the WNW. and WSW.; south winds those from the SSW. and SSE.; and east winds those from the ESE. and ENE.

Pairs of wind directions will be considered separately; the argument as to what should take place will first be stated, and thereafter the proof or otherwise *deducted* from actual observations and tabulations applied. This is a correct scientific mode of procedure.

North and South Winds.

The north is a decided land wind and the south a sea one; of that there is no doubt, and we should expect to find more of the former of a morning and of the latter of an evening. Such, in fact, is borne out by the observations, for the north wind blew at 8 a.m. upon 169 out of 212 occasions, while the south wind was blowing at 8 p.m. upon 57 out of 87 occasions.

The north 8 a.m. observations compared with the 8 p.m. ones are placed side by side on the following table:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	6	1	8	13	26	29	26	26	11	11	9	3	169
P.M. ...	0	1	0	4	2	5	8	13	6	2	1	1	43

An examination of this table shows that the north wind was more prevalent during the winter months, May to August, than during the rest of the year.

A further examination shows that the following were the wind directions on the previous evenings:—

Followed.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	14	12	95	20	3		16	2	2	169

It is noteworthy to notice that the west wind changed to north more than any other wind.

The south 8 a.m. and 8 p.m. observations are also placed side by side for comparison:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	1	4	6	5	1	0	0	4	2	0	3	4	30
P.M. ...	7	4	8	5	2	3	2	3	4	6	7	6	57

This is not so marked as the north wind, but the excess of evening observations over the morning ones can be traced. In this case there are more winds from this direction during summer than during the winter months, which is natural.

A further examination is made, as in the case of the north wind, showing the wind directions on the previous mornings:—

Followed.	N.	NW.	W.	SW.	E.	SE.	E.	NE.	C.	Total.
Times	2	3	16	14		3	5	3	5	57

The principal previous directions are from the west and south-west; this is the true evening veer.

North-West and South-West Winds.

The former, blowing off the land, should be a morning wind, and the latter, off the sea, should be an evening one. If the normal direction be west it is evident that the cooling of the air over the land will cause a backing to the north-west, but when the land is heated a south-west will blow.

The 8 a.m. and 8 p.m. observations for the north-west wind were as follows:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M.	3	11	11	9	16	12	15	18	16	17	6	12	146
P.M.	0	1	2	3	13	7	11	3	2	6	1	2	51

These show a great preponderance of winds from this direction of a morning as against those of an evening.

Similar observations for the south-west wind were as follows:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M....	6	6	6	2	1	5	2	2	4	5	7	3	49
P.M....	24	15	17	10	10	7	6	12	8	9	17	11	146

Here the excess rests with the evening observations.

Both these show the influences of land and sea breeze conditions.

An examination of the morning north-west observations shows that the following were the wind directions on the previous evenings:—

Followed.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	8	22	92	7	1	5	4	7	0	146

A similar examination of the south-west observations shows that the following were the previous morning directions:—

Followed.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	16	13	52	17	4	1	18	11	14	146

It will be seen from those two tables that in the majority of cases the wind either veered or backed from the west, this being the prevailing wind.

Looking at the evening north-west and the morning south-west winds, namely, those outside the land and sea breeze influence, it will be seen that the north-west was more prevalent during winter than during summer, but that there was a slight indication that the reverse was the case with the south-west winds.

South-East and North-East Winds.

The former, blowing from the sea, should be an evening wind, and the latter, blowing from the land, a morning one. The 8 a.m. and 8 p.m. observations were as follows:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M....	2	6	6	2	2	1	3	0	8	7	4	3	44
P.M....	17	21	17	9	8	9	7	12	13	17	22	19	171

The evening observations are vastly in excess of the morning ones.

Similar observations for the north-east wind are now given:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M....	6	8	11	23	32	35	37	22	11	12	8	4	209
P.M....	0	3	0	3	15	14	16	5	2	0	4	0	62

These were more numerous of a morning than of an evening. These two sets of observations clearly show the effect of land and sea breeze influences.

An examination of the winds at the previous observations gives the following results:—

For the South-East Winds.

Followed.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	11	2	10	10	4	24	76	21	13	171

For the North-East Winds.

Followed.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	5	8	88	15	3	15	39	31	5	209

The result is peculiar, for while the south-east followed the east in the majority of cases, the north-east followed that on 39 occasions, but 88 times it was preceded by a west wind. This latter is evidently due to the influence of the Mozambique hot sea current, which, by heating the air above it, influences the coastal winds to a considerable extent; this has been found to be the case from observations of barometric pressure. The west is a land wind in the true sense of the term, but the north-east is only one in relation to the east or south-east winds, which are strictly sea winds; so it will be better not to take notice of the swing from west to north-east in studying a question of this kind.

Looking at the south-east evening observations, there is a falling off from April to September inclusive, the full effect of this wind being felt during summer. The north-east evening observations are the reverse of this, for they are more numerous in winter than in summer, as are also the morning observations. In fact, taken as a whole, the summer majority rests with the south-east, and the winter one with the north-east winds.

To fully appreciate to what an extent the Mozambique sea current effects the coastal wind directions, the following table comprising all the observations of winds during the four years, has been prepared; and it will be seen that in the great majority of cases, both morning and evening the wind was blowing from the west. The east wind comes next in importance, and these two can be called the normal directions, the others being more or less land and sea breezes, oscillating therefrom.

Total Wind Observations during Four Years.

	N.	NW.	W.	SW.	S.	SE.	E.	NE.
A.M. ...	169	146	415	49	30	44	274	209
P.M. ...	43	51	643	146	57	171	229	62
Totals...	212	197	1058	195	87	215	503	271

West and East Winds.

These, as before stated, can be considered as normal directions, but still there is a difference between them. At Port Elizabeth the east wind is a sea wind and the west a land one, so one would expect to find more observations of the former of an evening and of the latter of a morning.

Here are the tables of the 8 a.m. and 8 p.m. observations:—

East Wind.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M.	38	22	27	21	16	9	14	19	22	28	31	27	274
P.M.	21	17	17	30	22	16	18	19	18	24	17	10	229

West Wind.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M.	49	44	39	34	18	20	18	20	34	38	41	60	415
P.M.	51	47	55	48	42	54	49	58	62	55	50	72	643

The fact brought out is that neither the west nor the east wind can be said to be in any way influenced by land and sea breeze conditions as compared with one another. There is, however, a decided tendency for the east wind to blow more as an evening one during the winter months, from April to August; but otherwise these are purely normal in their directions, and blow quite contrary to the land and sea breezes.

We can now tabulate the foregoing facts as follows:—

Number of times the W. and NW. winds went to the SW. of an evening		65
Number of times the SW. and W. winds went to the NW. of a morning		99
Number of times the SW. continued		17
Number of times the NW. continued		22
		203
Total number of SW. night winds	146	
Total number of NW. morning winds	146	
		292

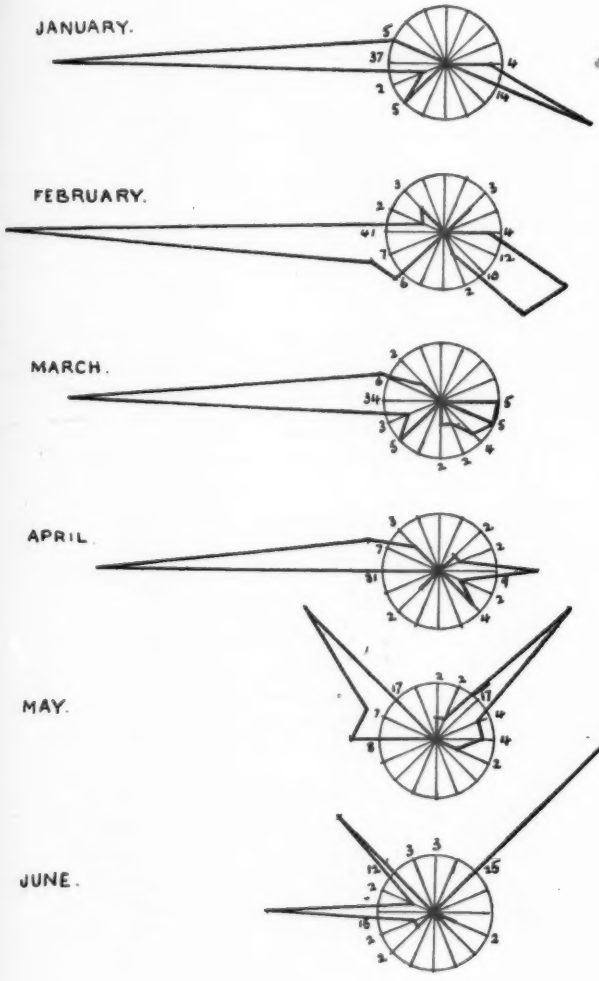
So that true displacing land and sea breezes blew upon 203 occasions out of 292.

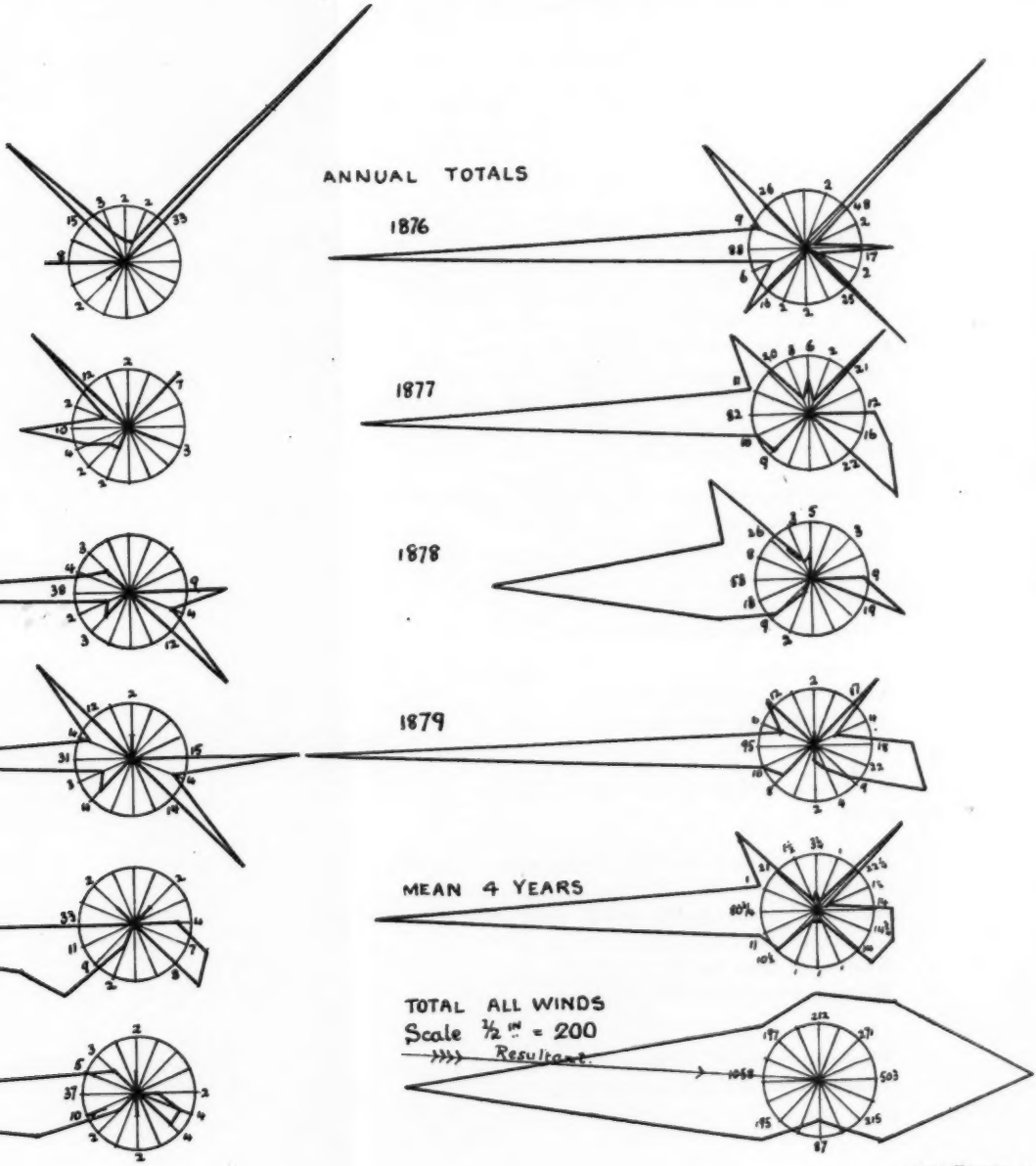
Number of times E. and NE. winds went to the SE. of an evening		97
Number of times the SE. and E. winds went to the NE. of a morning		54
Number of times the SE. continued		24
Number of times the NE. continued		31
		206
Total number of SE. night winds	171	
Total number of NE. morning winds	209	
		380

WIND PERSISTENCY ROSE, PORT ELIZABETH

MONTHLY TOTALS, 1876–1879.

Scale 1 In. = 15.





West, Newman proc.

So that true displacing land and sea breezes blew upon 206 occasions out of 380.

Both these are high percentages.

At present nothing can be stated as to the time of day when a wind changed, and until an investigation of self-recording instruments has been made the matter must remain in abeyance.

Taking the east and west components together, we get :—

Total number of night winds	171 + 146 = 317
Total number of morning winds.....	209 + 146 = 355
	672

Total number of veering and backing winds, 409.

409 = 60·86 per centum of 672.

We will tabulate our facts in another form :—

Normal Winds.

	A.M.	P.M.
Number of times for west winds.....	415	643
Number of times for east winds	274	229

Morning, or Land Winds.

Number of times for NW. winds.....	146	51
Number of times for NE. winds	209	62
Number of times for N. winds.....	169	43
	524	156

Evening, or Sea Winds.

Number of times for SW. winds	49	146
Number of times for SE. winds	44	171
Number of times for S. winds	30	57
	123	374

Although the west and east winds have been defined as normal, still if they displace winds from other directions, and are not continuous, this may be the result of land and sea breeze influence; that is to say, with the morning west winds and the evening east ones the continuous winds will represent normal conditions, and the remainder those influenced as before stated.

In the following tables for preceding winds it will be seen that the so-called normal east and west winds can be considerably reduced :—

West, A.M.

Following.	N.	NW.	W.	SW.	S.	SE.	E.	NE.	C.	Total.
Times	13	6	237	46	11	24	55	15	8	415

East, P.M.

Times	27	1	14	5	8	6	96	55	17	229

Taking the west winds first, it will be seen that they were normal upon 178 occasions, leaving a balance of 237 as shifting winds.

So with the east winds, these were normal upon 96 occasions, leaving a balance of 133 as shifting winds.

With reference to the east winds, it will be noticed that a large percentage of the previous winds were from the NE. ; this is the true backing for a sea breeze displacing a land one, *i.e.*, NE. to E.

Now, do the west and east winds, analysed as entities apart from other winds, show signs of following land and sea breeze influences? In the foregoing arguments ESE., E., and ENE. have been taken as equivalent to an east wind, and WNW., W., and WSW. as equivalent to a west one.

If these be separated the foregoing contention can either be proved or disproved.

The following gives the days when WNW. winds prevailed :—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M.	14	8	9	8	10	7	7	7	8	9	10	19	116
P.M.	2	3	4	9	7	5	0	4	5	3	2	5	49

The following are for the WSW. direction :—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M.	4	5	4	1	0	2	2	6	4	4	9	13	54
P.M.	19	15	15	12	9	10	18	17	18	17	14	24	188
												Total, both winds	407

It will be borne in mind that 1,058 observations were made of west winds ; by deducting the WSW. and WNW. ones, totalling 407, we get 651 as the actual number of true west winds. By comparing the two tables it is patent that the WNW. is more of a morning wind and the WSW. more of an evening one, the correct swing of land and sea breezes.

There is another point to consider in connection with west winds. If land and sea breeze conditions affect the three components, we should expect that towards the evening a veering would take place from WNW.

to W., or from W. to WSW.; and that towards the morning there would be a backing from WSW. to W., or from W. to WNW. The following tables bring out this argument, and prove it:—

WNW. veered to W., or W. to WSW.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	1	2	3	1	1	0	0	2	1	1	2	6	20
P.M. ...	14	11	6	11	4	6	7	4	6	10	9	19	107

WSW. backed to W., or W. to WNW.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	9	9	4	6	4	7	6	3	6	9	8	12	83
P.M. ...	1	2	0	3	2	1	1	2	0	2	2	3	19

The east wind must be similarly considered. Separating the three components, the tendency should be for the ENE. to blow of a morning and the ESE. of an evening.

The following gives the days when the ENE. winds prevailed:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	3	1	7	9	7	3	6	8	4	2	2	1	53
P.M. ...	0	0	0	1	3	1	1	0	0	1	0	0	7

The following gives the days when the ESE. winds prevailed:—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
A.M. ...	12	8	6	2	3	1	3	3	4	7	12	10	71
P.M. ...	16	13	11	6	3	5	6	10	12	13	11	7	113
												Total, both winds	244

In all 503 observations were made of east winds; by deducting the ENE. and ESE. ones we obtain 259 as the actual number of true east winds.

If land and sea breeze conditions affect the three components, we should expect a veering in the evening from ENE. to E., or from E. to ESE.; and a backing of a morning from ESE. to E., or from E. to ENE. As a matter of fact, the NE. and SE. winds play such an important part that any such veering and backing of the east winds are completely masked, the number of instances being too small to be of use.

Persistency of Wind Directions.

The following investigations, although not applying to land and sea breezes, have been included here as a fitting conclusion to this paper. Sometimes for a whole twenty-four hours, sometimes for days, the wind will continue to blow from the same direction, and this has been studied under the title of Wind Direction Persistency. All cases where wind

blew from one direction, covering two or more continuous observations, have been included; only those which blew during one observation have been put aside.

In this investigation the wind rose has been divided into sixteen points.

It has been found that the north-west and north-east winds blew more persistently during winter than during summer; but the west ones were more persistent during summer, as were also the east winds.

There was an entire absence of persistency from the south-east during winter, but this was compensated for during summer; this is in direct opposition to the north-east winds.

All wind persistencies are in accordance with the monthly distribution of barometric pressure, as the following table will show :—

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug	Sept.	Oct.	Nov.	Dec.	Total.
N.	0	0	0	0	2	3	2	2	0	2	0	2	13
NNW.	0	0		0	0	3	3	0	0	0	0	0	6
NW.	0	3	2	3	17	12	15	12	3	12	2	3	84
WNW.	5	2	6	7	7	2	0	2	4	4	0	5	44
W.	37	41	34	31	8	15	8	10	38	31	33	37	323
WSW.	2	7	3	0	0	2	0	4	2	3	11	10	44
SW.	5	6	5	2	0	2	2	2	3	4	9	2	42
SSW.	0	0	0	0	0	0	0	2	0	0	2	0	4
S.	0	0	2	0	0	0	0	0	0	0	0	2	4
SSE.	0	2	2	0	0	0	0	0	0	0	0	0	4
SE.	0	10	4	4	0	0	0	0	12	14	8	4	56
ESE.	14	12	5	2	2	2	0	3	4	4	7	4	59
E.	4	4	5	9	4	0	0	0	9	15	4	2	56
ENE.	0	0	0	2	4	0	0	0	0	0	0	0	6
NE.	0	3	0	2	17	25	33	7	0	0	2	0	89
NNE.	0	0	0	0	2	0	2	0	0	0	0	0	4

Taking the Annual Wind Rose for persistent winds, we get the following table :—

	1876.	1877.	1878.	1879.	Total.
N.	0	6	5	2	13
NNW.	0	3	3	0	6
NW.	26	20	26	12	84
WNW.	9	11	18	6	44
W.	88	82	58	95	323
WSW.	6	10	18	10	44
SW.	16	9	9	8	42
SSW.	2	0	2	0	4
S.	2	0	0	2	4
SSE.	0	0	0	4	4
SE.	25	22	0	9	56
ESE.	2	16	19	22	59
E.	17	12	9	18	56
ENE.	2	0	0	4	6
NE.	48	21	3	17	89
NNE.	2	2	0	0	4

This shows the preponderance of persistency in the west wind, the NW. and NE. equally coming in second.

The plates give in diagram form the various wind roses based on the foregoing table; they show conclusively how the persistence of the west wind falls off during the winter months.

The Annual Roses are worthy of consideration. It will be remembered that 1878 was a very wet year over the west, bringing up the yearly total of rainfall to a great height. It will be noticed how the west arm shortens from 1876 to 1878, and it is very strange that in the annual returns the persistency of the west wind failed altogether during May in the years 1877 and 1878; in the latter this failure extended to June and July. The year 1879 was a very dry one over the west, and it will be seen that the west arm of the rose stretches out to its maximum.

There must be, therefore, some connection between the rainfall over the west and the persistency of the west wind at Port Elizabeth, decreasing it in severe winters over the west, and increasing it in dry, but what that relationship is remains for the future to demonstrate.

This condition is brought out in the Monthly Totals Rose. Here the west wind prevails during the months which are dry over the west, and fails during months when it is wet, so there must be something more than accident in it.

It is evident from the foregoing investigation that at all times of the year, unless seriously affected by disturbances of sufficient magnitude to override them, land and sea breezes are to be traced in the winds at Port Elizabeth, and no reason can be assigned for doubting such a condition elsewhere along the coast. That such exists over the Cape Peninsula is more than probable, but for the present this point has not received sufficient consideration, although it is hoped that before long the winds of this portion of South Africa may be investigated in a similar manner to what has herein been done for Port Elizabeth.

GRAPHICAL REPRESENTATION OF SOME OF THE SIMPLER ANALYTIC FUNCTIONS OF A COMPLEX VARIABLE.

By E. T. Littlewood, M.A., B.Sc.

(Read October 19, 1910.)

1. A uniform function $w=f(z)$, where $z=x+iy$, may be completely represented in a model in the following manner:—

Modulus.—At each point of the (horizontal) z plane erect a vertical line of height h equal to $|w|$. The upper extremities of these lines will form a surface which will be called the "modular surface."

Argument.—Construct a family of curves in the z plane such that the tangent to one of them at any point is parallel to the vector w corresponding to that point. It will be shown in § 5 that these curves are the "stream lines" of a liquid moving irrotationally in a certain manner in two dimensions. Hence they will be called the "stream lines" of the function w.

The idea of the "modular surface," and the complete representation of a function by means of a model I believe to be original.

The modular surface and stream lines of an analytic function have certain simple and interesting relations, as will now be shown.

2. *Contour Lines and Lines of Greatest Slope.*—Let a system of contour lines and their orthogonal trajectories, the lines of greatest slope, be traced on the modular surface. The orthogonal projections of the contour lines on the z plane are evidently lines along which h, *i.e.*, $|w|$, is constant, or "lines of constant modulus," while the projections of the lines of greatest slope are their orthogonal trajectories.

It can easily be shown from elementary principles that the latter curves are also lines of "constant argument," and, since arg w is constant, it is evident that—

$$\frac{dh}{|dz|}=\frac{|dw|}{|dz|}=|w'|.$$

Thus the *gradient of the line of greatest slope* vertically above any point represents the *modulus of the differential coefficient* at that point. It will

further be seen that the *argument of the differential coefficient* is the ***angle at which the stream line is cut by the line of constant argument.***

3. *Divergence and Curvature of Stream Lines.*—Suppose the stream lines cut by a family of orthogonal trajectories, which we may call "cross lines." Let ds and dc be the respective (scalar) elements of arc of the stream line and corresponding cross line at z. If arg $w = \psi$, we have $w = he^{i\psi}$, whence—

$$w' = \frac{w}{h}\frac{dh}{dz} + iw\frac{d\psi}{dz} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

(a) Let dz be taken along the stream line. Then—

$$\arg dz = \arg w \text{ and } |dz| = ds,$$

therefore—

$$\frac{dz}{ds} = \frac{w}{h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Now w' is constant for all directions at z. Hence, combining (1) and (2)—

$$w' = \frac{dh}{ds} + ih\frac{d\psi}{ds} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

(b) Let dz be taken along the cross line. Then—

$$\arg dz = \arg (iw),$$

$$|dz| = dc \quad \text{and} \quad |iw| = h,$$

therefore—

$$\frac{dz}{dc} = i\frac{w}{h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Combining (1) and (4)—

$$w' = -i\frac{dh}{dc} + h\frac{d\psi}{dc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

From (3) and (5)—

$$\frac{dh}{ds} + ih\frac{d\psi}{ds} = -i\frac{dh}{dc} + h\frac{d\psi}{dc}.$$

Equating real and imaginary parts—

$$\frac{1}{h}\frac{dh}{ds} = \frac{d\psi}{dc}, \quad \text{and} \quad -\frac{1}{h}\frac{dh}{dc} = \frac{d\psi}{ds}.$$

We may call $\frac{d\psi}{dc}$, the curvature of the cross line, the "divergence" of the stream line at the point.

Thus, as we proceed along a stream line the gradient of the line on the modular surface, which lies vertically over it, is proportional to the divergence, while as we cross a stream line from concave to convex the gradient is proportional to the curvature of the stream line.

Hence a straight stream line indicates that the modulus is stationary as we cross it, and parallel stream lines indicate that the modulus is constant as we proceed along them.

4. *Stream Lines at Zero Points.*—If $f(z)$ has a zero at a, we may in general put $f(z)=(z-a)\phi(z)$, where $\phi(z)$ is finite. Then—

$$\arg f(z)-\arg(z-a)=\arg \phi(a) \text{ ultimately,}$$

and is approximately constant for a small circle round a.

Hence the stream lines make a constant angle with the radii drawn from the zero.

Infinite points will not be discussed generally, but special cases occur in z^{-1} and $\log z$, treated below.

5. *Determination of Stream Lines.*—One or more of the following methods may be used :—

(1) At a point of a stream line whose angle of contingence is ψ—

$$\psi=\arg w=\arg f(x+iy),$$

and it may be possible to plot ψ at a number of arbitrary points from the principle that—

$$\arg w_1+\arg w_2=\arg (w_1w_2),$$

and to sketch the stream lines in an approximative manner.

(2) Solution of the differential equation—

$$\frac{dy}{dx}=\tan \arg f(x+iy).$$

(3) The method of conjugate functions,* which is the method most generally useful.

Let—

$$w=u+iv,$$

then—

$$\frac{dz}{w}=\frac{dx+idy}{u+iv}=\frac{udx+vdy}{u^2+v^2}+i\ \frac{udy-vdx}{u^2+v^2}.$$

Both the real and imaginary parts of the last expression can be shown to be complete differentials. Hence we may write $\frac{dz}{w}=d\mathrm{C}+id\mathrm{S}$, where C and S are real functions of x and y.

* *Vide* acknowledgment at end of paper.

Integrating, we have—

$$C+iS=\int\frac{dz}{w}=\text{a function of } (x+iy).$$

Thus C is the velocity potential and S the stream function of a liquid moving irrotationally in two dimensions. Moreover, since along a stream line $udy-vdx=0$, and along a cross line $udx+vdy=0$, we see that S=constant, and C=constant are the respective equations of the stream lines, as defined in § 1, and the corresponding cross lines.

The following case includes several of those which follow :—

If—

$$w=z^n,\ n=1$$

$$C+iS=\int\frac{dz}{z^n}=-\frac{z^{-n+1}}{n-1}.$$

$$=-\frac{\cos(n-1)\theta-i\sin(n-1)\theta}{(n-1)r^{n-1}},$$

where r, θ are the polar co-ordinates of z. Hence the stream lines are given by—

$$\frac{\sin(n-1)\theta}{r^{n-1}}=\text{constant}.$$

6. *Construction of Models.*—I have constructed models,* in which the modular surface is suggested by a wire framework, through which the stream lines drawn on the horizontal base are visible. The wires for the most part follow vertical sections and contour lines, which were previously traced on paper from the functional equation.

In all cases except $\log z$ the functions are symmetrical about the real axis, and only the portion on one side of this is represented. This allows the framework to be attached to one side of a board, one face of which represents the vertical plane through the real axis.

It is possible that plaster of Paris or plasticine might be found a better material than wire.

7. *Illustrated Examples.*—The general characters of the models are shown in the following diagrams, which are accompanied by brief notes.

In each case but the last the thick line in the upper half represents the section of the modular surface by a vertical plane through the real axis, while the lower half represents (horizontal) stream lines.

A numerical factor k is introduced in most cases to reduce the elevation suitably, while the stream lines are unaffected.

* These were exhibited at the meeting.

1. $w = k(z - a)$.

No diagram shown, but modular surface a right circular cone, with axis vertical and vertex at a.

Stream lines, found from $C + iS = \int \frac{dz}{z-a}$, a family of straight lines radial at a.

2. (i.) $w = k(z^2 - a^2)$. (Fig. 1.)

Modular surface rises from two conical zeros, and tends to a paraboloid of revolution at infinity.

Stream lines, found from—

$$C + iS = \int \frac{dz}{z^2 - a^2},$$

a system of coaxial circles intersecting at zeros.

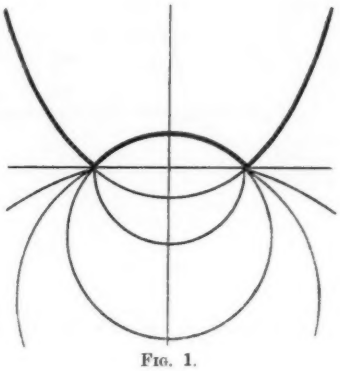


Fig. 1.

(ii.) $w = k(z^2 + a^2)$ (Fig. 2.)

Modular surface, the above turned through a right angle.

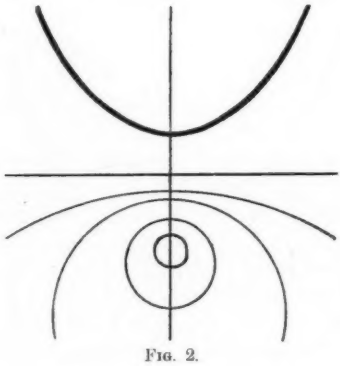


Fig. 2.

Stream lines, a system of coaxial circles, of which the zeros are limiting points.

By shifting the origin along the real axis the general quadratic function—

$$k(x^2 + px + q)$$

reduces to form (i.) or (ii.) according as $p^2 - 4q$ is positive or negative.

[In the models constructed, $k = \cdot 1$ and $a = 5$, unit of length being a centimetre.]

(iii.) $w = kz^2$.

Cases (i.) and (ii.) reduce to this when $a = 0$, and origin becomes a double zero. Modular surface a paraboloid of revolution. Stream lines a family of circles touching real axis at origin.

3. $w=\frac{1}{z}$ (Fig. 3.)

Modular surface obtained by rotating a rectangular hyperbola about an asymptote.

Stream lines given by—

$$r^2 \sin 2\theta = \text{constant},$$

a family of rectangular hyperbolas asymptotic to the real and imaginary axes. Origin an infinite point.

Note the infinite curvature at origin.

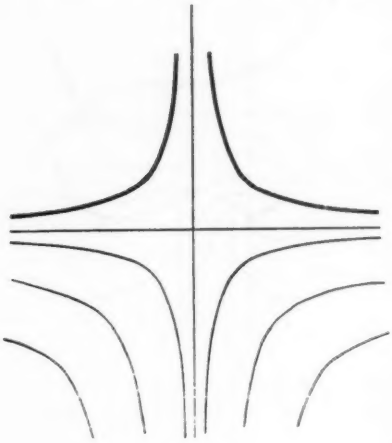


Fig. 3.

4. (i.) $w=k(z+a)z(z-b)$ (Fig. 4),

where a and b are real and positive.

[In the model constructed—

$$k=\cdot 02,\ a=5,\ b=10,$$

unit of length a centimetre.]

Modular surface rises from three zeros, and tends to a paraboloid of revolution of the third degree at infinity.

Stream lines might be found by method (3), but more easily plotted by method (1). They tend to Bernoulli's lemniscates at infinity, as in Fig. 6.

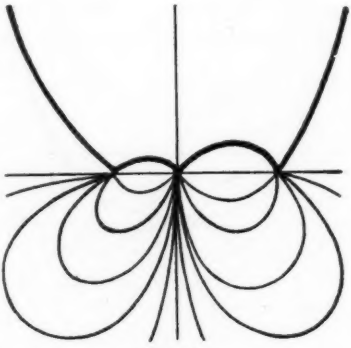


Fig. 4.

(ii.) $w=k(z^2+a^2)(z-b)$. (Fig. 5.)

[In models constructed—

$$k=\cdot 01,\ a=4\sqrt{3},\ b=12,$$

i.e., three zeros at angular points of equilateral triangle.]

Stream lines plotted as in (i.). Also tend to Bernoulli's lemniscates at infinity, as in Fig. 6.

The above illustrate a cubic equation, (i.) with three real roots, (ii.) with two imaginary roots.

(iii.) $w=kz^3$. (Fig. 6.)

Cases (i.) and (ii.) reduce to this when—

$$a=b=0.$$

Origin a triple zero.

Modular surface a paraboloid of revolution of third degree.

Stream lines, given by—

$$\frac{r^2}{\sin 2\theta}=\text{constant},$$

a family of Bernoulli's lemniscates.

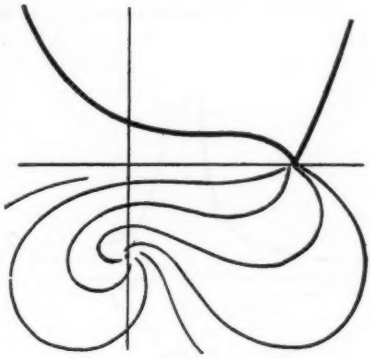


Fig. 5.

5. $w^2=kz$. (Fig. 7.)

Modular surface obtained by rotating half a parabola about tangent at vertex.

Stream lines, given by $r(1-\cos\theta)=\text{constant}$, a system of parabolas with origin as focus.

A case of a multiform function, the two sheets of the modular surface corresponding to the two branches being coincident. Note that one circuit round origin reverses direction of stream line, *i.e.*, increases argument by π.

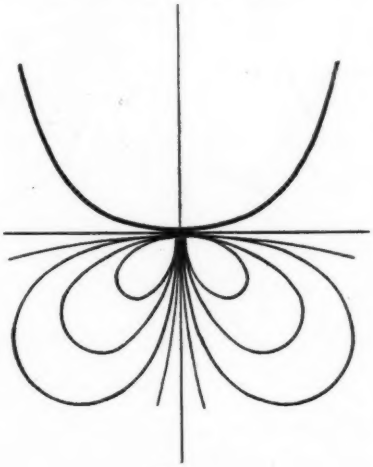


Fig. 6.

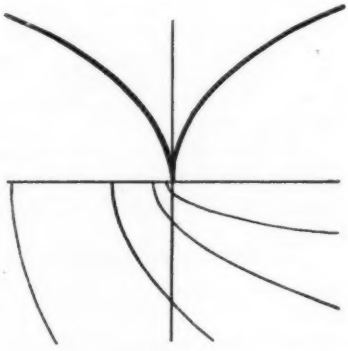


Fig. 7.

6. $w=e^z$. (Fig. 8.)

Modular surface cylindrical, with generators parallel to imaginary axis. Vertical section the exponential curve.

Stream lines best found by method (2), by solving—

$$\frac{dy}{dx}=\tan y,$$

giving—

$$x+c=\log(\pm\sin y),$$

a system of curves asymptotic to—

$$y=\pm n\pi.$$

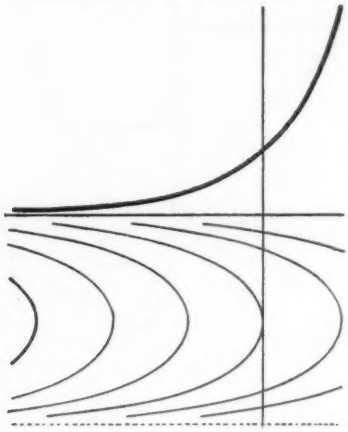


Fig. 8.

7. $w=\cos z$. (Fig. 9.)

[In model constructed, unit of length = 3 centimetres.]

Here—

$$h^2=\frac{1}{2}(\cosh 2y+\cos 2x).$$

Modular surface rises from infinite row of zeros—

$$\pm\tfrac{1}{2}\pi,\quad \pm\tfrac{3}{2}\pi,\ \&c.,$$

and rapidly tends to become cylindrical, with generators parallel to real axis.

Vertical section through real axis gives $\cos x$, with lower parts inverted, and is shown in upper part of figure.

Vertical sections through imaginary axis and parallel to it at distance $\frac{1}{2}\pi$ give $\cosh y$ and $\sinh y$ respectively, and are shown by thick and dotted lines in lower part of figure.

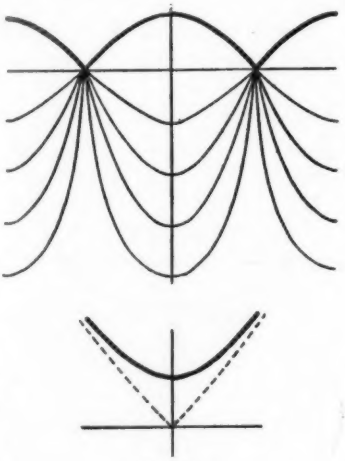


Fig. 9.

Stream lines, derived from—

$$C+iS=\int\frac{dz}{\cos z}$$
$$=\log(\sec z+\tan z),$$

given by—

$$\frac{\sinh y}{\cos x}=\text{constant},$$

a family of curves intersecting at zeros.

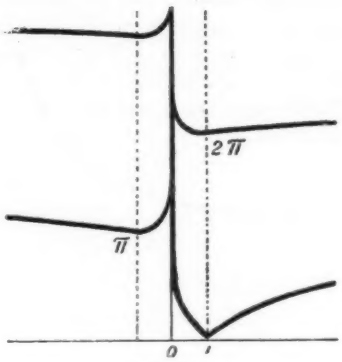


Fig. 10.

8. $w=\log z$.

Here—

$$h^2=(\log r)^2+\theta^2.$$

Modular surface, a continuous spiral surface, winding upwards round a vertical axis through the origin.

When $r=1$, $h=\theta$, a helix of unit pitch. It can be shown to be a line of greatest slope, its projection on the z plane being a line of constant argument $\frac{1}{2}\pi$.

From this helix the surface curls up inwards round the axis and becomes asymptotic to it.

Vertical sections through real axis Fig. 10), obtained when—

$$\theta=0,\ \pi,\ 2\pi,\ \&c.$$

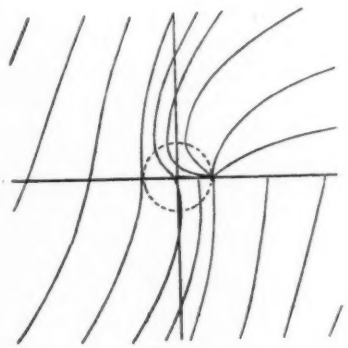


Fig. 11.

Stream lines (Fig. 11) plotted from—

$$\tan\psi=\frac{\theta}{\log r}.$$

Discontinuity along real axis apparent only, as stream lines belong to different parts of surface.

[In the model the upper part is made wholly of wire tied by helical pieces and suitable vertical supports.]

In conclusion, I have to thank Mr. R. A. Herman, of Cambridge, for his criticism of the paper in its original form, as a consequence of which, while the results and diagrams are unaffected, I have improved the methods of arriving at them, in particular by adopting the method of conjugate functions in finding stream lines. I am also indebted to my son, Mr. J. E. Littlewood, for some useful suggestions, and to Professor Crawford, of the South African College, for criticism of the paper in its final form.

UPON THE FOURTH ORDER PERTURBATIONS IN THE MOTIONS OF SATELLITES III. AND IV. OF JUPITER.

By R. T. A. Innes, F.R.A.S., F.R.S.S.Af.

(Read March 15, 1911.)

In addition to the well-known relations amongst the mean-motions of the three inner great satellites of Jupiter, there is the approximate relation—

$$7n_4 - 3n_3 = 0^\circ{\cdot}0448$$

between the mean-motions of III. and IV., which gives rise to inequalities of the fourth order of the eccentricities. These inequalities are largely increased by the motions of the lines of apsides which are of the same order of magnitude as $7n_4 - 3n_3$. The period of the largest coefficient is about twenty-seven years.

In the *Bulletin Astronomique*, vol. ix., de Haerdtl called attention to these inequalities, and computed their effect so far as the longitude of III. is affected. M. E. de Haerdtl combines all the terms into one, viz.—

$$\partial l_3 = +6''{\cdot}49\mathrm{S}(7l_4 - 3l_3 + 114^\circ{\cdot}8),$$

[See postscript on notation at end of paper]

in which the suffix $_3$ applies to Satellite III. and $_4$ to IV. This combination of the various terms into one is, however, illegitimate, because of the rapid motions of the apsides.

In his new tables of the great satellites Professor Sampson states that he has included every inequality which he found amounted to 1″, but none of the above-mentioned inequalities is shown, so that it would appear from Professor Sampson's calculations that they are all under 1″. I have therefore made a new calculation, of which the details are presented.

The inequalities in question are given in seconds of arc by the following equations:—

$$\partial l_3 = +9\frac{m_4 a n_3^2}{1+m_3}\,\frac{e_3^i e_4^j \mathrm{P}^{i,j}\rho''}{(7n_4 - 3n_3 - j\dot{\omega}_4 - i\dot{\omega}_3)}\,\mathrm{S}(7l_4 - 3l_3 - j\omega_4 - i\omega_3)$$

$$\partial l_4 = -21\frac{m_3 n_4^2}{1+m_4} \times \frac{e_3^i e_4^j \mathrm{P}^{i,j}\rho''}{(7n_4 - 3n_3 - j\dot{\omega}_4 - i\dot{\omega}_3)}\,\mathrm{S}(7l_4 - 3l_3 - j\omega_4 - i\omega_3).$$

The values of the $P^{i,j}$ required are as follows:—

$$
\begin{aligned}
+384\,P^{4,0} &= [\ 9681 + 3736\mathbf{D} + 557\mathbf{D}_2 + 38\mathbf{D}_3 + \mathbf{D}_4]\,b_{7,1}\\
-\ 96\,P^{3,1} &= [10452 + 4067 + 602 + 40 + \ ]\,b_{6,1}\\
+\ 64\,P^{2,2} &= [11175 + 4408 + 649 + 42 + \ ]\,b_{5,1}\\
-\ 96\,P^{1,3} &= [11768 + 4751 + 698 + 44 + \ ]\,b_{4,1}\\
+384\,P^{0,4} &= [12085 + 5088 + 749 + 46 + \ ]\,b_{3,1}
\end{aligned}
$$

The values of $\mathbf{D}_p b_{r,1}$ have been calculated with $La = 9{\cdot}7547600–10$, and the formulæ given in the *Monthly Notices of the Royal Astronomical Society*, vols. lxix., No. 8, and lxx., No. 2, and are as follows:—

r.	$\mathbf{D}_0 b_{r,1}$.	$\mathbf{D}_1 b_{r,1}$.	$\mathbf{D}_2 b_{r,1}$.	$\mathbf{D}_3 b_{r,1}$.	$\mathbf{D}_4 b_{r,1}$.
0	2·1998213	0·4997520	1·528063	6·214157	34·36292
1	0·6558006	0·8790111	1·808692	6·433653	34·83472
2	0·2842813	0·6768853	1·919493	7·176498	37·23956
3	0·1358364	0·4622008	1·728920	7·528608	40·49590
4	0·0679279	0·2999804	1·405845	7·228600	42·54063
5	0·0348807	0·1892447	1·069453	6·426559	42·23997
6	0·0182250	0·1172292	0·776788	5·374925	39·58104
7	0·0096402	0·0716994	0·545466	4·284580	35·20792

A general checking equation will be found in M.N.R.A.S., vol. lxx., No. 2, p. 195, line 4 from foot. If therein we put $m = 3$, $n = 1$, and $i = 7$ we easily obtain—

$$\mathbf{D}_3(\mathbf{D} + 7)b_{7,1} = a(\mathbf{D} + 1)^3(\mathbf{D} + 7)b_{6,1};$$

or—

$$(\mathbf{D}_4 + 7\mathbf{D}_3)b_{7,1} = a(\mathbf{D}_4 + 10\mathbf{D}_3 + 24\mathbf{D}_2 + 22\mathbf{D}_1 + 7\mathbf{D}_0)b_{6,1},$$

whence—

$$65{\cdot}19998 = 65{\cdot}19991.$$

Again, in the same general equation, put $i = -6$; then after expansion—

$$(\mathbf{D}_4 - 6\mathbf{D}_3)b_{6,1} = a(\mathbf{D}_4 - 3\mathbf{D}_3 - 15\mathbf{D}_2 - 17\mathbf{D}_1 - 6\mathbf{D}_0)b_{7,1},$$

whence—

$$7{\cdot}33149 = 7{\cdot}33157.$$

These two checks are more than sufficiently correct for our present purpose.

In calculating the above quantities, some of the numbers involved were found to be as follows:—

$$
\left.\begin{aligned}
L\,\beta^2 &= 9{\cdot}6790830–10\\
L\,p_{11} &= 9{\cdot}9801637–10\\
L\,p_7 &= 9{\cdot}9686574–10
\end{aligned}\right\}\ \text{See M N, Vol. lxix., No. 8.}
$$

$$
\begin{aligned}
L\,b_{0,1} &= 0{\cdot}3423874\\
L\,b_{7,1} &= 7{\cdot}9840858–10
\end{aligned}
$$

The above yield—

$$L\,P^{4,0} = 0{\cdot}351701$$
$$L\,P^{3,1} = 1{\cdot}160576n$$
$$L\,P^{2,2} = 1{\cdot}542166$$
$$L\,P^{1,3} = 1{\cdot}569966n$$
$$L\,P^{0,4} = 1{\cdot}169637$$

If these figures are compared with de Haerdtl's (*Bull. Astr.*, ix., p. 215) a grave discordance will be found in the last, but de Haerdtl's figures can be reproduced if, in his formula, we replace $52b_3^{(9)}$, which is correct, by $520b_3^{(9)}$, which is erroneous.

We also have—

$$L\,m_3 = \quad 5{\cdot}90244\text{–}10 \text{ (Sampson)}$$
$$L\,m_4 = \quad 5{\cdot}65360\text{–}10 \text{ (Sampson)}$$
$$Le_3 \;= \quad 7{\cdot}18070\text{–}10 \text{ (de Sitter)}^*$$
$$Le_4 \;= \quad 7{\cdot}87017\text{–}10 \text{ (de Sitter)}$$
$$L\,n_3 = \quad 1{\cdot}7017203$$
$$L\,n_4 = \quad 1{\cdot}3338724$$
$$\dot{\omega}_3 \quad = +0^\circ{\cdot}0069513$$
$$\dot{\omega}_4 \quad = +0^\circ{\cdot}0018975$$

from which we get—

$$L\;\; 9\frac{m_3 a n_3^2}{1+m_3}\rho'' = 5{\cdot}08047$$

$$L\;21\frac{m_2 n_4^2}{1+m_4}\rho'' = 5{\cdot}20683$$

$$L\,(7n_4 - 3n_3 - 0\dot{\omega}_4 - 4\dot{\omega}_3) = 8{\cdot}23104\text{–}10$$
$$L\,(7n_4 - 3n_3 - 1\dot{\omega}_4 - 3\dot{\omega}_3) = 8{\cdot}34394\text{–}10$$
$$L\,(7n_4 - 3n_3 - 2\dot{\omega}_4 - 2\dot{\omega}_3) = 8{\cdot}43346\text{–}10$$
$$L\,(7n_4 - 3n_3 - 3\dot{\omega}_4 - 1\dot{\omega}_3) = 8{\cdot}50765\text{–}10$$
$$L\,(7n_4 - 3n_3 - 4\dot{\omega}_4 - 0\dot{\omega}_3) = 8{\cdot}57099\text{–}10$$

With these numbers we have finally :—

Argument.	δl_3.	δl_4.
$S\,(7l_4 - 3l_3 - 0\omega_4 - 4\omega_3)$	$+0''{\cdot}00$	$-0''{\cdot}01$
$S\,(7l_4 - 3l_3 - 1\omega_4 - 3\omega_3)$	$-0{\cdot}09$	$+0{\cdot}12$
$S\,(7l_4 - 3l_3 - 2\omega_4 - 2\omega_3)$	$+0{\cdot}72$	$-0{\cdot}96$
$S\,(7l_4 - 3l_3 - 3\omega_4 - 1\omega_3)$	$-2{\cdot}67$	$+3{\cdot}57$
$S\,(7l_4 - 3l_3 - 4\omega_4 - 0\omega_3)$	$+3{\cdot}88$	$-5{\cdot}19$

It should be remembered that the mean values of e_3 and e_4, and the mean values of the motions of the apsides have been employed, so that the perturbations shown are mean values. Thus as e_3 is variable to the

* See *Kon. Akad. v. Wetenschappen te Amsterdam*, April 24, 1908.

extent of about 40 per cent. of its mean value, the figures in the 4th line (2″·67 and 3″·57) are very nearly similarly variable.

It will be seen that several of these inequalities exceed Professor Sampson's limit.

TRANSVAAL OBSERVATORY.
November 21, 1910.

P.S.—In this paper an attempt to use a logical mathematical notation has been introduced. Its chief point is that capital letters are reserved for functional symbols or operators and lower-case letters for symbols of quantity. The translation is exceedingly simple, viz. :—

New Notation.	Old Notation.
S	sin
L	log to base 10, or $\log_{10}$
L	log to natural base, or $\log_e$
D	$a\frac{d}{da}$
$\mathbf{D}_2$	$a\frac{d}{da}\left(a\frac{d}{da}\right)$
D	$\frac{d}{da}$
ρ''	radian in seconds of arc

The **D** (clarendon type), although easy and conspicuous in print, is difficult to write; it might be written $\overline{\mathrm{D}}$, a note being added in MS. for print that $\overline{\mathrm{D}}$ is to be printed in clarendon type.

SYLVESTER'S AND OTHER UNISIGNANTS.

By Thomas Muir, LL.D., F.R.S.

(Read March 15, 1911.)

1. The first to draw attention to the existence of determinants having their final development free of negative terms appears to have been Sylvester. In the *Quarterly Journal of Mathematics*, i. (1855), pp. 42–56, when dealing with the subject of the change of independent variables in certain differential expressions, he was brought up against an n-line determinant of the type

$$\begin{vmatrix} a+a_2+a_3 & -a_2 & -a_3 \\ -b_1 & b+b_3+b_1 & -b_3 \\ -c_1 & -c_2 & c+c_1+c_2 \end{vmatrix},$$

which, after some investigation, he asserted to contain in the final form of its development nothing but positive terms. No proof was adduced of the assertion; and, save that he gave a rule-of-thumb for obtaining the development referred to, no light was thrown on the peculiar constitution of the determinant.

2. Evidently it may be defined with reasonable minuteness as *the determinant which has its non-diagonal elements all negative, but the sum of the elements of each row positive.* Note may also be taken that the number of variables is the same as in a general determinant, but that those associated with the diagonal have the peculiarity of being equal to the sums of the rows. Another ready deduction from the definition is that *every co-axial minor of such a determinant is a determinant of the same kind.* (I.)

3. The property of unisignancy is most easily established by making the nth case depend on the $(n-1)$th and lower cases, and by the use of Cayley's development proceeding according to products of the variables special to the diagonal. Thus, on the supposition that the cases for the second and third orders have been established, we take the case for the fourth order, the determinant then being

$$\begin{vmatrix} a+a_2+a_3+a_4 & -a_2 & -a_3 & -a_4 \\ -b_1 & b+b_1+b_3+b_4 & -b_3 & -b_4 \\ -c_1 & -c_2 & c+c_1+c_2+c_4 & -c_4 \\ -d_1 & -d_2 & -d_3 & d+d_1+d_2+d_3 \end{vmatrix}$$

and develop it according to products of a, b, c, d. The cofactor of $abcd$ is seen to be 1; the cofactors of abc, abd, acd, bcd to be

$$d_1+d_2+d_3, \quad c_1+c_2+c_4, \quad b_1+b_3+b_4, \quad a_2+a_3+a_4;$$

the cofactors of $ab, ac, \ldots$ to be two-line determinants which by hypothesis are unisignant; the cofactors of a, b, c, d to be three-line determinants which are also unisignant for the same reason; and the aggregate of remaining terms, namely, those independent of a, b, c, d to be a determinant which vanishes because the sum of the elements of its every row is zero. The final development therefore consists of nothing but positive terms, the number of them being

$$1+4\cdot3+6\cdot8+4\cdot16, \quad i.e., \ 125,$$

or $(4+1)^{4-1}$ in agreement with Sylvester's statement.

In a sense, the result is a special case of the general theorem that *if all the coaxial minors of a determinant be in their final development free of negative terms, any positive quantities added to the diagonal elements will not affect the unisignancy.*

4. Of much more importance, however, is the fact, strangely overlooked by Sylvester, and indeed not hitherto noticed, that *the determinant obtained from his by changing the signs of all the non-diagonal elements is also free of negative terms in its final development.* (II.)

For this the same mode of proof suffices, but the final portion of it brings up a difficulty which is wanting in the other case, and which on investigation leads to specially interesting results.

Denoting Sylvester's determinant when of the nth order by S_n, and that now referred to by T_n, we readily see that

$$T_2 = S_2 = ab + a_2b + ab_1,$$
$$T_3 = S_3 + 2(a_2b_3c_1 + a_3b_1c_2);$$

that in T_4 the cofactors of $abcd, abc, abd, acd, bcd, ab, ac, ad, bc, bd, cd$ are identical with the corresponding cofactors in S_4; that the cofactors of a, b, c, d are greater by

$$2(b_3c_4d_2 + b_4c_2d_3), \ 2(a_3c_4d_1 + a_4c_1d_3), \ 2(a_2b_4d_1 + a_4b_1d_2), \ 2(a_2b_3c_1 + a_3b_1c_2);$$

but that the aggregate of the terms free of a, b, c, d, namely,

$$\begin{vmatrix} a_2+a_3+a_4 & a_2 & a_3 & a_4 \\ b_1 & b_3+b_4+b_1 & b_3 & b_4 \\ c_1 & c_2 & c_4+c_1+c_2 & c_4 \\ d_1 & d_2 & d_3 & d_1+d_2+d_3 \end{vmatrix},$$

instead of being 0 as in the case of S_4 or even being known to be unisignant, requires special investigation.

This, therefore, we proceed to give, and in doing so will for shortness' sake write

$$a_{234},\quad b_{12},\quad \ldots \quad \text{for} \quad a_2+a_3+a_4,\quad b_1+b_2,\quad \ldots$$

and denote the determinant itself by $2\mathfrak{T}_4$.

5. At the outset we note that much may be learned regarding its constitution by making transpositions of rows followed by the like transpositions of columns. Thus, by passing the first row over all the others, and thereafter moving the first column in the same way, it is seen that the determinant is invariant to the triad of cyclic substitutions

$$\left.\begin{array}{l} a_2,\ b_3,\ c_4,\ d_1 = b_3,\ c_4,\ d_1,\ a_2 \\ a_3,\ b_4,\ c_1,\ d_2 = b_4,\ c_1,\ d_2,\ a_3 \\ a_4,\ b_1,\ c_2,\ d_3 = b_1,\ c_2,\ d_3,\ a_4 \end{array}\right\}$$

or, what is the same thing, the pair

$$\left.\begin{array}{l} a,\ b,\ c,\ d = b,\ c,\ d,\ a \\ 1,\ 2,\ 3,\ 4 = 2,\ 3,\ 4,\ 1 \end{array}\right\} \qquad \text{(III.)}$$

Again, by passing the second row over the remaining rows and thereafter moving the second column in the same way, we deduce the existence of invariance to the quartet of cyclic substitutions

$$\left.\begin{array}{l} \left.\begin{array}{l} a_2,\ a_3,\ a_4 = a_3,\ a_4,\ a_2 \\ b_1,\ c_1,\ d_1 = c_1,\ d_1,\ b_1 \end{array}\right\} \\ \left.\begin{array}{l} b_3,\ c_4,\ d_2 = c_4,\ d_2,\ b_3 \\ b_4,\ c_2,\ d_3 = c_2,\ d_3,\ b_4 \end{array}\right\} \end{array}\right\} \qquad \text{(IV.)}$$

Both of these results have their advantages as assisting in finding the final development and as affording a means of abbreviating the expressions for the same.

6. We then seek a form of $\mathfrak{T}_4$ more suitable for development, and obtain

$$\mathfrak{T}_4 = \begin{vmatrix} a_{234} & a_2 & a_3 & a_4 \\ b_{341} & b_{341} & b_3 & b_4 \\ c_{412} & c_2 & c_{412} & c_4 \\ d_{123} & d_2 & d_3 & d_{123} \end{vmatrix} = \begin{vmatrix} . & a_2 & a_3 & a_4 \\ -b_{34} & b_{341} & b_3 & b_4 \\ -c_{24} & c_2 & c_{412} & c_4 \\ -d_{23} & d_2 & d_3 & d_{123} \end{vmatrix}$$

$$= \begin{vmatrix} . & a_2 & a_3 & a_4 \\ -b_{34} & b_1 & -b_4 & -b_3 \\ -c_{24} & -c_4 & c_1 & -c_2 \\ -d_{23} & -d_3 & -d_2 & d_1 \end{vmatrix}. \qquad \text{(V.)}$$

As each of the a's in the last form occurs in only one place, all that remains necessary in view of (IV.) is to develop the cofactor of one of them, say the cofactor of a_2, which

$$= \begin{vmatrix} b_{34} & -b_4 & -b_3 \\ c_{24} & c_4 & -c_2 \\ d_{23} & -d_2 & -d_1 \end{vmatrix} = \begin{vmatrix} . & -b_4 & -b_3 \\ c_{14} & \cdots c_4 & -c_2 \\ d_{13} & -d_2 & d_1 \end{vmatrix},$$

$$= c_{14}(b_4d_1 + b_3d_2) \; + \; d_{13}(b_4c_2 + b_3c_1);$$

the whole result thus is

$$\begin{aligned} \mathfrak{T}_4 = \quad & a_2 \left\{ (c_1+c_4)\,(b_4d_1+b_3d_2) + (d_1+d_3)\,(b_4c_2+b_3c_1) \right\} \\ & + a_3 \left\{ (d_1+d_2)\,(c_2b_1+c_4b_2) + (b_1+c_4)\,(c_2d_2+c_4d_1) \right\} \\ & + a_4 \left\{ (b_1+b_2)\,(d_3c_1+d_2c_4) + (c_1+d_2)\,(d_3b_4+d_2b_1) \right\}, \end{aligned} \qquad \text{(VI.)}$$

so that $\mathfrak{T}_4$ is a determinant whose final development consists of 24 positive terms.

7. An alternative and equally important result is obtained by observing that in (V.) solitary positions are also occupied by b_1, c_1, d_1, namely,

$$\begin{aligned} \mathfrak{T}_4 = \quad & c_1d_1a_2b_{34} + b_1(a_4d_2c_{24} + a_3c_2d_{23}) \\ & + d_1b_1a_3c_{42} + c_1(a_2b_3d_{32} + a_4d_3b_{34}) \\ & + b_1c_1a_4d_{23} + d_1(a_3c_4b_{43} + a_2b_4c_{42}) \end{aligned} \Bigg\} + a_{234}(b_4c_2d_3 + b_3c_4d_2) \qquad \text{(VII.)}$$

where the aggregate of the terms free of b_1, c_1, d_1 is most readily got by going back to the original form of $\mathfrak{T}_4$ in § 4.*

8. Before proceeding to the consideration of $\mathfrak{T}_5$ it is necessary to point out that there are variant determinant forms of $\mathfrak{T}_4$ which, though of little value for development purposes, are well deserving of notice on other grounds. For example, there is the form

$$\begin{vmatrix} a_{234} & a_{34} & a_{24} & a_{23} \\ -b_{134} & . & -b_{14} & -b_{13} \\ -c_{124} & -c_{14} & . & -c_{12} \\ -d_{123} & -d_{13} & -d_{12} & . \end{vmatrix}$$

* Further, taking from (VII.) the portion free of the suffix 1, and using (III.) on it, we have

$$\begin{aligned} \mathfrak{T}_4 = \quad & (a_2+a_3+a_4)\,(b_4c_2d_3+b_3c_4d_2) \\ & + (b_2+b_3+b_4)\,(c_1d_2a_4+c_4d_1a_2) \\ & + (c_4+c_3+c_2)\,(d_2a_4b_1+d_1a_2b_4) \\ & + (d_1+d_2+d_3)\,(a_3b_1c_2+a_2b_3c_1) \end{aligned} \Bigg\} \qquad \text{(VIII.)}$$

This form, however, has no interest in connection with the general argument, as it is peculiar to $\mathfrak{T}_4$.

to which, as it is readily seen to have all its coaxial minors unisignant, the theorem quoted at the end of § 3 may be profitably applied, in order to obtain a unisignant of greater generality than $\mathfrak{T}_4$, namely,

$$\begin{vmatrix} a_{234} & a_{34} & a_{24} & a_{23} \\ -b_{134} & b_0 & -b_{14} & -b_{13} \\ -c_{124} & -c_{14} & c_0 & -c_{12} \\ -d_{123} & -d_{13} & -d_{12} & d_0 \end{vmatrix}, \text{ or, say, } \mathfrak{T}'_4.$$

The final development of this contains, in addition to the 24 terms of $\mathfrak{T}_4$, the 57 terms involved in

$$b_0c_0d_0.a_{234} + \Sigma c_0d_0.a_{34}b_{134} + \Sigma d_0(a_4b_{14}c_{14} + b_3a_{24}c_{14} + c_2a_{34}b_{14}) \qquad \text{(IX.)}$$

The variant forms of $\mathfrak{T}'_4$ which include the forms of $\mathfrak{T}_4$ used in § 6 are

$$\begin{vmatrix} a_{234} & a_2 & a_3 & a_4 \\ b_{134} & b_{1340} & b_3 & b_4 \\ c_{124} & c_2 & c_{1240} & c_4 \\ d_{123} & d_2 & d_3 & d_{1230} \end{vmatrix}, \quad \begin{vmatrix} . & a_2 & a_3 & a_4 \\ -b_{034} & b_1 & -b_{04} & -b_{03} \\ -c_{024} & -c_{04} & -c_1 & -c_{02} \\ -d_{023} & -d_{03} & -d_{02} & d_1 \end{vmatrix},$$

$$\begin{vmatrix} . & a_2 & a_3 & a_4 \\ -b_{034} & b_{0134} & b_3 & b_4 \\ -c_{024} & c_2 & c_{0124} & c_4 \\ -d_{123} & d_2 & d_3 & d_{0123} \end{vmatrix}; \qquad \text{(X.)}$$

and two others are

$$\begin{vmatrix} a_{234} & a_2 & a_3 & a_4 \\ -b_{01} & -b_1 & b_{04} & b_{03} \\ -c_{01} & c_{04} & -c_1 & c_{02} \\ -d_{01} & d_{03} & d_{02} & -d_1 \end{vmatrix}, \quad \begin{vmatrix} a_{234} & a_{34} & a_{24} & a_{23} \\ b_1 - b_0 & -b_0 & b_{14} & b_{13} \\ c_1 - c_0 & c_{14} & -c_0 & c_{12} \\ d_1 - d_0 & d_{13} & d_{12} & -d_0 \end{vmatrix},$$

these latter leading easily to the theorem that *if the vacant places in*

$$\begin{vmatrix} a_{234} & a_2 & a_3 & a_4 \\ -b_1 & -b_1 & & \\ -c_1 & & -c_1 & \\ -d_1 & & & -d_1 \end{vmatrix}, \quad \begin{vmatrix} a_{234} & a_{34} & a_{24} & a_{23} \\ -b_1 & -b_1 & & \\ -c_1 & & -c_1 & \\ -d_1 & & & -d_1 \end{vmatrix}$$

*be filled up with any positive elements whatever, the resulting determinants are unisignant.** (XI.)

9. Taking now $\mathfrak{T}_5$, and treating it as $\mathfrak{T}_4$ was treated in § 6, we find that the form of it corresponding to (V.) is

$$\begin{vmatrix} . & a_2 & a_3 & a_4 & a_5 \\ -b_{345} & b_1 & -b_{45} & -b_{35} & -b_{34} \\ -c_{245} & -c_{45} & c_1 & -c_{25} & -c_{24} \\ -d_{235} & -d_{35} & -d_{25} & d_1 & -d_{23} \\ -e_{234} & -e_{34} & -e_{24} & -e_{23} & e_1 \end{vmatrix}.$$

* From summing these two unisignants we reach a result already given in a paper on "Boole's Unisignant" in the *Proc. R. S. Edinb*, xxxi., pp. 448–455.

Next we see that in this the cofactor of a_2

$$= \begin{vmatrix} b_{345} & -b_{45} & -b_{35} & -b_{34} \\ c_{245} & c_1 & -c_{25} & -c_{24} \\ d_{235} & -d_{25} & d_1 & -d_{23} \\ e_{234} & -e_{24} & -e_{23} & e_1 \end{vmatrix} = \begin{vmatrix} b_{345} & b_3 & b_4 & b_5 \\ c_{245} & c_{1245} & c_4 & c_5 \\ d_{235} & d_3 & d_{1235} & d_5 \\ e_{234} & e_3 & e_4 & e_{1234} \end{vmatrix}$$

$$= \begin{vmatrix} . & b_3 & b_4 & b_5 \\ -c_{145} & c_2 & -c_{15} & -c_{14} \\ -d_{135} & -d_{15} & d_2 & -d_{13} \\ -e_{134} & -e_{14} & -e_{13} & e_2 \end{vmatrix},$$

—that is to say, is equal to a determinant of the form $\mathfrak{T}'_4$. We thus learn not only that $\mathfrak{T}_5$ is unisignant, but that the number of its terms is 4 times the number in $\mathfrak{T}'_4$.

In exactly similar fashion it is found that

$$\mathfrak{T}_6 = \Sigma[a_2 \times \text{determinant like } \mathfrak{T}'_5] \qquad \text{(XII.)}$$

where

$$\mathfrak{T}'_5 = \begin{vmatrix} . & a_2 & a_3 & a_4 & a_5 \\ -b_{3450} & b_1 & -b_{450} & -b_{350} & -b_{340} \\ -c_{2450} & -c_{450} & c_1 & -c_{250} & -c_{240} \\ -d_{2350} & -d_{350} & -d_{250} & d_1 & -d_{230} \\ -e_{2340} & -e_{340} & -e_{240} & -e_{230} & e_1 \end{vmatrix}.$$

The unisignancy of $\mathfrak{T}_n$ is thus established; and, as we have seen, this carries with it the unisignancy of T_n.

10. The number of the terms is most readily got, when we have reached this stage, by putting each of the variables equal to 1 in the original form of the two determinants. Thus, the number of terms in $\mathfrak{T}_5$

$$= \tfrac{1}{2}\begin{vmatrix} 4 & 1 & 1 & 1 & 1 \\ 1 & 4 & 1 & 1 & 1 \\ 1 & 1 & 4 & 1 & 1 \\ 1 & 1 & 1 & 4 & 1 \\ 1 & 1 & 1 & 1 & 4 \end{vmatrix} = \tfrac{1}{2} . 8 . 3^4 = 4 . 3^4;$$

and the number of terms in T_5 is $(5+4) . 4^4$. Generally, *the number in* $\mathfrak{T}_n$ *is*

$$(n-1)\,(n-2)^{n-1},$$

and the number in T_n *is*

$$(2n-1)\,(n-1)^{n-1} \qquad \text{(XIII.)}$$

Similarly, we find the number in $\mathfrak{T}'_n$ to be

$$(n-1)^n,$$

and we can thus verify the statement made above that the number in $\mathfrak{T}_n$ is $n-1$ times the number in $\mathfrak{T}'_{n-1}$.

11. Taking $\mathfrak{T}_5$ in the form used in § 9 and developing it according to products of the diagonal elements we obtain an alternative proof of its unisignancy. For the result of the development is

$$\mathfrak{T}_5 = \Sigma c_1 d_1 e_1 \begin{vmatrix} . & a_2 \\ -b_{345} & . \end{vmatrix} + \Sigma d_1 e_1 \begin{vmatrix} . & a_2 & a_3 \\ -b_{345} & . & -b_{45} \\ -c_{245} & -c_{45} & . \end{vmatrix}$$

$$+ \Sigma e_1 \begin{vmatrix} . & a_2 & a_3 & a_4 \\ -b_{345} & . & -b_{45} & -b_{35} \\ -c_{245} & -c_{45} & . & -c_{25} \\ -d_{235} & -d_{35} & -d_{25} & . \end{vmatrix} + \text{terms free of suffix 1,}$$

and in this it is readily seen that the sum of the terms free of the suffix 1 is equal to

$$\tfrac{1}{2} a_{2345} \times \text{determinant like } \mathbf{T}_4 ;$$

that the cofactor of e_1 is a determinant like $\mathfrak{T}'_4$; and, if we care to say so, that the cofactor of $d_1 e_1$ is a determinant like $\mathfrak{T}'_3$ and the cofactor of $c_1 d_1 e_1$ a determinant like $\mathfrak{T}'_2$: in other words, that all the determinants which appear in the development are unisignants.

12. Returning now to Sylvester's unisignant we have to note the curious theorem that *if it be bordered horizontally and vertically with the elements* 0, 1, 1, 1,... *the resulting determinant has in its final development nothing but* negative *terms.*

This is easily verified for the cases of S_2 and S_3, the number of terms in the one case being 6 and in the other 48. Supposing the verification has been made, let us examine the case of S_4, namely,

$$\begin{vmatrix} . & 1 & 1 & 1 & 1 \\ 1 & a_{0234} & -a_2 & -a_3 & -a_4 \\ 1 & -b_1 & b_{0134} & -b_3 & -b_4 \\ 1 & -c_1 & -c_2 & c_{0124} & -c_4 \\ 1 & -d_1 & -d_2 & -d_3 & d_{0123} \end{vmatrix}.$$

Taking the development according to products of a_0, b_0, c_0, d_0 we see that the cofactor of $b_0 c_0 d_0$ is -1; that the cofactor of $c_0 d_0$ is a bordered S_2, and therefore by hypothesis a negative unisignant: that the cofactor of d_0 is a bordered S_3, and therefore for the same reason a negative unisignant: and that the aggregate of the terms independent of the suffix 0 is the negative sum of the signed primary minors of

$$\begin{vmatrix} a_{234} & -a_2 & -a_3 & -a_4 \\ -b_1 & b_{134} & -b_3 & -b_4 \\ -c_1 & -c_2 & c_{124} & -c_4 \\ -d_1 & -d_2 & -d_3 & d_{123} \end{vmatrix},$$

and therefore is equal to 4 times the negative sum of the primary *coaxial*

minors, each of which is seen to be an S_3. The terms are thus all negative, the number being

$$4+6.8+4.48+4.4.16,$$
$$i.e.,\ 500.$$

In like manner the case of S_5 may next be established, then S_6, S_7, ...

13. The theorem just proved may also be stated as follows: *The sum of the signed primary minors of a Sylvester's unisignant is also unisignant.*

On putting all the variables equal to 1 in the bordered S_n, it is readily seen that the number of terms in it is n times the number in S_n itself, and therefore is

$$n(n+1)^{n-1}. \qquad \text{(XV.)}$$

14. Careful note should be taken of the fact that the like bordering of any other unisignant will not necessarily be attended with the same result. Thus in the case of the unisignant which most closely resembles S_n, namely T_n, the property does not hold. It holds, however, in the case of Boole's unisignant B_n, and in the case of the "new unisignant" M_n recently described by me in the *Messenger of Math.*, xl., pp. 177-192.

The last of these cases is by far the most interesting, as *the bordered unisignant is then transformable into a like unisignant of the next lower order*, the exact result for the third order being that *the sum of the signed primary minors of*

$$M(a_1, b_1b_2b_3, c_1c_2c_3)$$

is

$$M(b_1+c_1,\ b_2+c_2,\ b_3+c_3). \qquad \text{(XVI.)}$$

In order to make clear the mode of establishing this, let us take the more complicated case of M_4, where the sum of the signed primary minors is

$$-\begin{vmatrix} . & 1 & 1 & 1 & 1 \\ 1 & a+b_{234}+c_{123}+d_1 & a+b_{34}+c_1 & a+b_{24}+c_2 & a+b_{23}+c_3 \\ 1 & a+b_{34}+c_1 & a+b_{134}+c_{145}+d_2 & a+b_{14}+c_4 & a+b_{13}+c_5 \\ 1 & a+b_{24}+c_2 & a+b_{14}+c_4 & a+b_{124}+c_{246}+d_3 & a+b_{12}+c_6 \\ 1 & a+b_{23}+c_3 & a+b_{13}+c_5 & a+b_{12}+c_6 & a+b_{123}+c_{356}+d_4 \end{vmatrix},$$

The operations which transform this into

$$-\begin{vmatrix} . & 1 & 1 & 1 & 1 \\ 1 & c_{123}+d_1 & c_1-b_1 & c_2-b_1 & c_3-b_1 \\ 1 & c_1-b_2 & c_{145}+d_2 & c_4-b_2 & c_5-b_2 \\ 1 & c_2-b_3 & c_4-b_3 & c_{246}+d_3 & c_6-b_3 \\ 1 & c_3-b_4 & c_5-b_4 & c_6-b_4 & c_{356}+d_4 \end{vmatrix}$$

and then into

$$-\begin{vmatrix} . & 1 & 1 & 1 & 1 \\ 1 & b_1+c_{123}+d_1 & c_1 & c_2 & c_3 \\ 1 & c_1 & b_2+c_{145}+d_2 & c_4 & c_5 \\ 1 & c_2 & c_4 & b_3+c_{246}+d_3 & c_6 \\ 1 & c_3 & c_5 & c_6 & b_4+c_{356}+d_4 \end{vmatrix}$$

are not difficult to see. They suffice to show that *the sum of the signed primary minors of*

$$\mathrm{M}(a\,;\ b_1b_2b_3b_4\,;\ c_1c_2c_3c_4c_5c_6\,;\ d_1d_2d_3d_4)$$

is the same as the sum of the signed primary minors of

$$\mathrm{M}(0\,;\ 0000\,;\ c_1c_2c_3c_4c_5c_6\,;\ b_1+d_1,\ b_2+d_2,\ b_3+d_3,\ b_4+d_4) \quad \text{(XVII.)}$$

The next operations are

$$\begin{array}{lll} \mathrm{row}_3-\mathrm{row}_2, & \mathrm{row}_4-\mathrm{row}_2, & \mathrm{row}_5-\mathrm{row}_2 \\ \mathrm{col}_3-\mathrm{col}_2, & \mathrm{col}_4-\mathrm{col}_2, & \mathrm{col}_5-\mathrm{col}_2, \end{array}$$

which will be found to lead to

$$\begin{vmatrix} b_{12}+c_{2345}+d_{12} & b_1+c_{34}+d_1 & b_1+c_{25}+d_1 \\ b_1+c_{34}+d_1 & b_{13}+c_{1346}+d_{13} & b_1+c_{16}+d_1 \\ b_1+c_{25}+d_1 & b_1+c_{16}+d_1 & b_{14}+c_{1256}+d_{14} \end{vmatrix}$$

i.e., to

$$\begin{vmatrix} \overline{b_1+d_1}+c_{25}+c_{34}+\overline{b_2+d_2} & \overline{b_1+d_1}+c_{34} & \overline{b_1+d_1}+c_{25} \\ \overline{b_1+d_1}+c_{34} & b_1+d_1+c_{16}+c_{34}+\overline{b_3+d_3} & \overline{b_1+d_1}+c_{16} \\ \overline{b_1+d_1}+c_{25} & \overline{b_1+d_1}+c_{16} & \overline{b_1+d_1}+c_{16}+c_{25}+\overline{b_4+d_4} \end{vmatrix};$$

so that the sum of the signed primary minors of M_4 is equal to

$$\mathrm{M}(b_1+d_1\,;\ c_1+c_6,\ c_1+c_5,\ c_3+c_4\,;\ b_2+d_2,\ b_3+d_3,\ b_4+d_4).$$

By the usual method the number of terms in the final development of the bordered M_n is ascertained to be

$$n\,.\,2^{(n-2)(n-1)}. \quad \text{(XVIII.)}$$

SYLVESTER'S AXISYMMETRIC UNISIGNANT.

By Thomas Muir, LL.D., F.R.S.

(Read May 24, 1911.)

1. In a previous paper* it was suggested that the multilinear unisignant functions

$$a_2a_3+a_2b_3+a_3b_3,$$
$$a_2a_3a_4+a_2a_3(b_4+c_4)+a_2a_4(b_3+c_4)+a_3a_4(b_3+b_4)$$
$$+(a_2+a_3+a_4)\,(b_3b_4+b_3c_4+b_4c_4,$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

which are the final developments of the axisymmetric determinants

$$\begin{vmatrix} a_2+b_3 & -b_3 \\ -b_3 & a_3+b_3 \end{vmatrix}, \quad \begin{vmatrix} a_2+b_3+b_4 & -b_3 & -b_4 \\ -b_3 & a_3+b_3+c_4 & -c_4 \\ -b_4 & -c_4 & a_4+b_4+c_4 \end{vmatrix}, \quad \ldots\ldots\ldots$$

might with advantage be viewed apart altogether from the theory of determinants. In support of this it was shown that, the numbers of the variables being $2+1$, $3+2+1$, ..., the functions could be much more appropriately denoted by

$$\left|\left\{\begin{matrix} a_2 & a_3 \\ & b_3 \end{matrix}\right\}\right|, \quad \left|\left\{\begin{matrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{matrix}\right\}\right|, \quad \ldots\ldots\ldots,$$

and that with this notation a recurrent law of formation could be readily formulated, namely,

$$\left|\left\{a_2\right\}\right| \equiv a_2, \quad \left|\left\{\begin{matrix} a_2 & a_3 \\ & b_3 \end{matrix}\right\}\right| \equiv (a_2+a_3)\left|\left\{b_3\right\}\right| + a_2a_3,$$

$$\left|\left\{\begin{matrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{matrix}\right\}\right| \equiv (a_2+a_3+a_4)\left|\left\{\begin{matrix} b_3 & b_4 \\ & c_4 \end{matrix}\right\}\right| + a_2a_3\left|\left\{b_4+c_4\right\}\right| + a_2a_4\left|\left\{b_3+c_4\right\}\right| + a_3a_4\left|\left\{b_3+b_4\right\}\right| + a_2a_3a_4,$$

$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$

* Muir, T. "Borchardt's Form of the Eliminant of Two Equations of the nth Degree." *Trans. R. Soc. S. Africa*, I., pp 447–452.

2. In continuation attention is now called to the alternative series of identities,

$$|\{a_2\}| = a_2, \quad \left|\begin{Bmatrix} a_2 & a_3 \\ & b_3 \end{Bmatrix}\right| = a_2|\{b_3+a_3\}| + a_3|\{b_3\}|,$$

$$\left|\begin{Bmatrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{Bmatrix}\right| = a_2\left|\begin{Bmatrix} b_3+a_3 & b_4+a_4 \\ & c_4 \end{Bmatrix}\right| + a_3\left|\begin{Bmatrix} b_3 & b_4 \\ & c_4+a_4 \end{Bmatrix}\right| + a_4\left|\begin{Bmatrix} b_3 & b_4 \\ & c_4 \end{Bmatrix}\right|,$$

.....

where the function of the nth degree is expressed as the sum of n terms, each of which is the product of one of the elements of the first frame-line by a function of the next lower degree, and where the first term involves all the a's, the second term all the a's except one, the third term all the a's except two, and so on. To construct the development in any case, say the case of

$$\left|\begin{Bmatrix} a_2 & a_3 & a_4 & a_5 \\ & b_3 & b_4 & b_5 \\ & & c_4 & c_5 \\ & & & d_5 \end{Bmatrix}\right|,$$

we first delete the a's to obtain the minor which is the basis of the second factor of every term. Then we complete this minor for its place in the first term by increasing each of its b's by the corresponding a, for its place in the second term by increasing each of the c's in the same way, and so on, the result thus being

$$\begin{aligned} a_2\left|\begin{Bmatrix} b_3+a_3 & b_4+a_4 & b_5+a_5 \\ & c_4 & c_5 \\ & & d_5 \end{Bmatrix}\right| + a_3\left|\begin{Bmatrix} b_3 & b_4 & b_5 \\ & c_4+a_4 & c_5+a_5 \\ & & d_5 \end{Bmatrix}\right| \\ + a_4\left|\begin{Bmatrix} b_3 & b_4 & b_5 \\ & c_4 & c_5 \\ & & d_5+a_5 \end{Bmatrix}\right| + a_5\left|\begin{Bmatrix} b_3 & b_4 & b_5 \\ & c_4 & c_5 \\ & & d_5 \end{Bmatrix}\right| \end{aligned} \qquad \text{(I.)}$$

whence are obtained $50+35+24+16$, *i.e.*, 125 final terms.*

* A useful rule-of-thumb for obtaining the development in the case of the function of the 3rd order

$$\left|\begin{Bmatrix} x_2 & x_3 & x_4 \\ & y_3 & y_4 \\ & & z_4 \end{Bmatrix}\right|$$

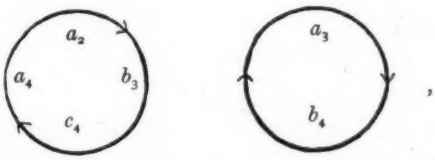
is: *Multiply x_2z_4 by the sum of the remaining elements, x_3y_4 by the similar sum, x_4y_3 by the similar sum, and make a term from the elements of each frame-line.*

It is convenient also to use $\mathbf{S}$ as the notational letter for the function, the degree being specified where necessary by a suffix.

3. By reason of the permutability of the frame-lines we have

$$\left|\begin{matrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{matrix}\right| = \left|\begin{matrix} b_3 & b_4 & a_2 \\ & c_4 & a_3 \\ & & a_4 \end{matrix}\right|;$$

and we thus see that the function is invariant to the simultaneously performed circular substitutions



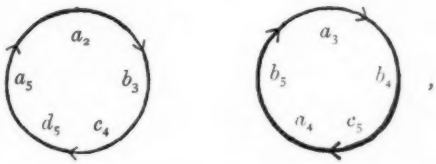
and can be expressed by

$$\overset{\circ}{\Sigma} a_2 a_3 a_4 + \overset{\circ}{\Sigma} a_2 b_3 c_4 + \overset{\circ}{\Sigma} a_2 a_3 b_4 + \overset{\circ}{\Sigma} a_2 b_4 c_4 + \overset{\circ}{\Sigma} a_2 a_3 c_4,$$

or

$$\overset{\circ}{\Sigma} a_2 a_3 (a_4 + b_4 + c_4) + \overset{\circ}{\Sigma} a_2 c_4 (b_3 + b_4).$$

Similarly it is found that the function of the 4th degree is invariant to the simultaneous circular substitutions



and so on for the 5th and higher degrees, the first substitution in each case being composed of the elements lying on the hypotenuse of the triangular array together with the element situated at the right angle of the same, and the remaining substitutions being similarly obtained from lines parallel to the hypotenuse. (II.)

4. Since the adjugate of a determinant is an integral power of the same, it follows that the adjugate of a unisignant can have only positive terms in its final development. It consequently becomes of interest to ascertain whether such an adjugate can be represented in a form which attests unisignancy. For the particular case of the unisignant $\mathfrak{S}$ the answer is in the affirmative, and a very interesting theorem is connected therewith.

In preparation for it it is necessary to recall the fact that a determinant with polynominal elements so constituted that all the elements of each coaxial minor have a term in common has nothing but positive terms in the final development: for example,

$$\begin{vmatrix} \alpha+\beta_2+\beta_3+\gamma_1 & \alpha+\beta_3 & \alpha+\beta_2 \\ \alpha+\beta_3 & \alpha+\beta_1+\beta_3+\gamma_2 & \alpha+\beta_1 \\ \alpha+\beta_2 & \alpha+\beta_1 & \alpha+\beta_1+\beta_2+\gamma_3 \end{vmatrix},$$

which is denoted by

$$\mathrm{M}(\alpha,\ \beta_1\beta_2\beta_3,\ \gamma_1\gamma_2\gamma_3) \quad \text{or} \quad \mathrm{M}_3,$$

has 32 positive and no negative terms.

Now the theorem just referred to is to the effect that the adjugate of $\mathfrak{S}_3$ is the M-unisignant of the 3rd order in which

$$\alpha=\left|\begin{matrix} b_3 & b_4 \\ & c_4 \end{matrix}\right|, \quad \gamma_1=\left|\begin{matrix} a_3 & a_4 \\ & c_4 \end{matrix}\right|, \quad \gamma_2=\left|\begin{matrix} a_2 & a_4 \\ & b_4 \end{matrix}\right|, \quad \gamma_3=\left|\begin{matrix} a_2 & a_3 \\ & b_3 \end{matrix}\right|,$$

$$\beta_1=a_4b_3, \quad \beta_2=a_3b_4, \quad \beta_3=a_2c_4.$$

The values of α, γ_1, γ_2, γ_3, it will be observed, are the minors of $\mathfrak{S}_3$ got by deleting its frame-lines in order: the fact that they constitute a set is in accordance with a previously known result, namely, that α is involved in the development of M_3 exactly as the γ's are.

Similarly the adjugate of $\mathfrak{S}_4$ is the M-unisignant of the 4th order

$$\mathrm{M}(\alpha\,;\ \beta_1\beta_2\beta_3\beta_4\,;\ \gamma_1\gamma_2\gamma_3\gamma_4\gamma_5\gamma_6\,;\ \delta_1\delta_2\delta_3\delta_4)$$

where

$$\alpha,\ \delta_1,\ \delta_2,\ \delta_3,\ \delta_4$$

have the values

$$\left|\begin{matrix} b_3 & b_4 & b_5 \\ & c_4 & c_5 \\ & & d_5 \end{matrix}\right|, \ \left|\begin{matrix} a_3 & a_4 & a_5 \\ & c_4 & c_5 \\ & & d_5 \end{matrix}\right|, \ \left|\begin{matrix} a_2 & a_4 & a_5 \\ & b_4 & b_5 \\ & & d_5 \end{matrix}\right|, \ \left|\begin{matrix} a_2 & a_3 & a_5 \\ & b_3 & b_5 \\ & & c_5 \end{matrix}\right|, \ \left|\begin{matrix} a_2 & a_3 & a_4 \\ & b_3 & b_4 \\ & & c_4 \end{matrix}\right|;$$

the β's the values

$$a_2\left|\begin{matrix} c_4 & c_5 \\ & d_5 \end{matrix}\right|, \quad a_3\left|\begin{matrix} b_4 & b_5 \\ & d_5 \end{matrix}\right|, \quad a_4\left|\begin{matrix} b_3 & b_5 \\ & c_5 \end{matrix}\right|, \quad a_3\left|\begin{matrix} b_3 & b_4 \\ & c_4 \end{matrix}\right|;$$

and the γ's the values

$$b_3\left|\begin{matrix} a_4 & a_5 \\ & d_5 \end{matrix}\right|, \ b_4\left|\begin{matrix} a_3 & a_5 \\ & c_5 \end{matrix}\right|, \ b_5\left|\begin{matrix} a_3 & a_4 \\ & c_4 \end{matrix}\right|, \ c_4\left|\begin{matrix} a_2 & a_5 \\ & b_5 \end{matrix}\right|, \ c_5\left|\begin{matrix} a_2 & a_4 \\ & b_5 \end{matrix}\right|, \ d_5\left|\begin{matrix} a_2 & a_3 \\ & b_3 \end{matrix}\right|.$$

Here, as before, the first set of values, five in number, consists of the primary minors of $\mathbb{S}_4$ in its triangular form; and the remaining values, ten in number, are obtained by multiplying any element of $\mathbb{S}_4$ by the corresponding secondary minor, that is to say, by the minor got by deleting the two frame-lines to which the element belongs. (III.)

5. From the preceding it is incidentally seen that *the primary minors of a Sylvester's axisymmetric unisignant are also unisignants though of a different kind.* (IV.)

In the case of $\mathbb{S}_4$ the primary minors that are coaxial, being of the form

$$\alpha+(\beta_2+\beta_3+\beta_4)+(\gamma_1+\gamma_2+\gamma_3)+\delta_1,$$

have

$$16+9+9+16, \quad i.e., \quad 50$$

terms; and the non-coaxial, being of the form

$$\alpha+(\beta_3+\beta_4)+\gamma_1$$

have

$$16+6+3 \quad i.e., \quad 25$$

terms.

From this it follows that the number of terms in the adjugate of $\mathbb{S}_4$

$$=\begin{vmatrix} 50 & 25 & 25 & 25 \\ 25 & 50 & 25 & 25 \\ 25 & 25 & 50 & 25 \\ 25 & 25 & 25 & 50 \end{vmatrix}$$

$$= 25^4.5 = 5^9 = (5^3)^3,$$

which agrees with the fact that the adjugate of $\mathbb{S}_4$ is $(\mathbb{S}_4)^3$ coupled with the fact the number of terms in $\mathbb{S}_4$ is 5^3.

6. The theorem (IV.) includes a theorem previously known, namely, that the sum of the primary minors of β is unisignant, and this again implies that the axisymmetric bordering of $\mathbb{S}$ by 0,1,1,1,... gives a determinant whose final terms are all negative. It is thus suggested to ascertain the character of the final development of the determinant obtained by bordering $\mathbb{S}$ axisymmetrically by $0,x,y,z,...$

Taking first the case of $\mathbb{S}_2$, which when bordered as indicated becomes

$$\begin{vmatrix} . & x & y \\ x & a_2+b_3 & -b_3 \\ y & -b_3 & a_3+b_3 \end{vmatrix}$$

we see that the latter has all its terms negative, being equal to

$$-a_2y^2-a_3x^2-b_3(x+y)^2.$$

Proceeding similarly with the next case we see that

$$\begin{vmatrix} . & x & y & z \\ x & a_2+b_3+b_4 & -b_3 & -b_4 \\ y & -b_3 & a_3+c_4+b_3 & -c_4 \\ z & -b_4 & -c_4 & a_4+b_4+c_4 \end{vmatrix}$$

$$= -a_3a_4x^2-a_4a_2y^2-a_2a_3z^2+a_2\begin{vmatrix} . & y & z \\ y & c_4+b_3 & -c_4 \\ z & -c_4 & b_4+c_4 \end{vmatrix}+a_3\begin{vmatrix} . & x & z \\ x & b_3+b_4 & -b_4 \\ z & -b_4 & b_4+c_4 \end{vmatrix}$$

$$+a_4\begin{vmatrix} . & x & y \\ x & b_3+b_4 & -b_3 \\ y & -b_3 & c_4+b_3 \end{vmatrix}+\begin{vmatrix} . & x & y & z \\ x & b_3+b_4 & -b_3 & -b_4 \\ y & -b_3 & c_4+b_3 & -c_4 \\ z & -b_4 & -c_4 & b_4+c_4 \end{vmatrix},$$

where each of the three-line determinants is an example of the previous case. As for the four-line determinant, we have only to perform the operations

$$\text{row}_4+\text{row}_3+\text{row}_2, \quad \text{col}_4+\text{col}_3+\text{col}_2$$

to find that it is equal to

$$-(x+y+z)^2.\begin{vmatrix} b_3+b_4 & -b_3 \\ -b_3 & c_4+b_3 \end{vmatrix}$$

i.e., $$-(x+y+z)^2\,(b_3b_4+b_3c_4+b_4c_4).$$

The conclusion thus again is that all the terms of the final development are negative.

That this is generally true is due to the fact that, having proved it true when all the a's vanish, we can then make each case dependent on those preceding it. (V.)

COLLOIDAL GOLD AND "PURPLE OF CASSIUS."

By James Moir, M.A., D.Sc., F.C.S., F.R.S.S.Af.

(Read March 15, 1911.)

A number of experiments have been done to test the generally-accepted view that "purple of Cassius" is a solid-solution of colloidal gold in hydrated stannic oxide. When once formed, the purple resists cold pure *aqua regia*, in this respect differing from pure finely-divided gold. Nearly all the experiments were made with a very dilute solution of $HAuCl_4$ in distilled water, made so as to contain 5 parts gold in 1,000,000 of water.

Acid solution of $SnCl_2$ alone produces a pale yellowish-brown coloration of remarkable stability, the relationship of which to purple of Cassius, from which it is obviously different, is obscure. This yellow coloration is unaffected by caustic potash even when used in quantity sufficient to redissolve the tin precipitate first formed; nor is it affected by boiling or the addition of neutral salts or of hydrazine, which would be expected to coagulate it if it were merely due to extreme fineness of division of precipitated gold. It even resists chlorine water and nitric acid (when not in excess), but strong HCl alters it to brown and then to a pink shade, and *aqua regia* slowly develops the purple of Cassius shade. Curiously enough, in this process the absorption-spectrum scarcely alters, beyond a slight increase in the amount of violet transmitted. When stronger solutions are employed the brown solution obtained by using $SnCl_2$ alone has an olive-green pseudo-fluorescence in reflected light, whereas purple of Cassius (use of $SnCl_4 + SnCl_2$) has an orange-red reflection, probably due to metallic gold. When the gold solution is made strongly acid before adding $SnCl_2$, the shade produced is pink, *i.e.*, metallic gold is liberated.

In order to obtain purple of Cassius from $HAuCl_4$ and $SnCl_2$, the presence of an oxidant with loosely-bound oxygen is necessary. Dilute HNO_3 (free from HNO_2) has no effect, whereas even a trace of *aqua regia* which has been heated so as to form HNO_2 and chlorine acts at once. Chlorine water and euchlorine behave similarly. *Aqua regia* from pure acids, and not heated, has remarkably little action. Addition of a trace of sodium nitrite before the $SnCl_2$ gives an intense pink shade of the purple of Cassius. An excess of nitrite, however, prevents the formation

of any colour at all—this is probably due to the gold being rendered unavailable, by conversion into $KAu(NO_2)_2$, analogous to aurocyanide, in which the gold is part of the anion—it being well known that $SnCl_2$ has no action on gold compounds of this nature. Excess of caustic alkali appears to behave similarly by converting the gold into $KAuO_2$, which does not react with stannous compounds. Iodine solution followed by strong acid and $SnCl_2$ gives a good purple.

Some experiments were tried to get the purple shade without the presence of tin. Addition of hydrazine sulphate to the faintly acid gold solution has no immediate effect, but a blue-purple shade develops in half a minute or so. Hydrazine hydrate (or its sulphate followed by alkali) gives the same blue-purple shade immediately; this shows that the tin in purple of Cassius is merely a vehicle for the finely-divided gold and does not enter into chemical combination with it.

If *aqua regia* or chlorine water be added to the very dilute gold solution, and then hydrazine sulphate, the action is much inhibited, but eventually a pale pink coloration appears. This is evidently the shade produced by gold in its finest state of division, as was also proved by Bredig in his electrically-prepared colloidal gold solutions. The purple shade is produced by larger particles and the blue shade by still larger ones. Addition of salts to the pink solutions causes coagulation and change of colour through purple to blue and grey; conversely, when a gold leaf is thinned by cyanide its transmission colour changes from green to violet. The pinkest shade is obtained by still slower precipitation, *e.g.*, by adding an alkaline solution of glycerol to $HAuCl_4$—but however slow, the shade is never yellow-brown like the $SnCl_2$ product, which latter is therefore unique and not due simply to colloidal gold. It would be interesting to apply the ultramicroscope to this problem (if there were one in S.A.!). The yellow substance may possibly be colloidal AuCl, and the effect of strong HCl in slowly turning it pink may be due to its keeping it in solution and enabling it to be reduced to metallic gold. Curiously enough, Johannesburg tap-water when added to $HAuCl_4$ generally produces a brown coloration of similar nature from the action of contained organic matter.

Neither hydrogen peroxide nor nitrous acid reduce very dilute $HAuCl_4$ solutions, and hydroxylamine acts very slowly unless alkaline.

Good imitations of solid purple of Cassius are obtainable by adding $MgCl_2$ or $ZnCl_2$ to $HAuCl_4$ solutions and then adding caustic soda containing a trace of hydrazine. Alumina on the contrary gives a dirty grey and $BaSO_4$ does not combine at all.

SOME REMARKABLE OXIDATION-PRODUCTS OF BENZIDINE.

By James Moir, M.A., D.Sc., F.C.S., F.R.S.S.Af.

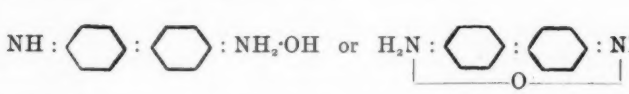
(Read March 15, 1911.)

The two substances discussed in this paper are prepared by oxidising benzidine with chromic acid and with potassium ferricyanide respectively, and their formation has long been known, the reactions indeed serving as the best tests for benzidine in nearly neutral solution. The two substances closely resemble indigo in appearance—very dark-blue needles, insoluble in all solvents except strong mineral acids, and possessing a distinct coppery reflex; nevertheless, they are described in the literature as simple chromate and ferricyanide of benzidine, on the authority of their respective discoverers, viz., Julius (*Monatshefte*, 1884, p. 192, also *Sitzungsber.* 1884, p. 78) and Barzilowsky (*Journ. Russ. chem. Ges.*, 17, p. 366).

It is, of course, obvious nowadays that a colourless base must give a *yellow* chromate and ferricyanide, and that therefore these dark-blue substances must be salts of an oxidation-product of benzidine. Curiously enough, Julius considered this possibility and rejected it. He found on treating the blue chromate with ammonia, that he recovered a small quantity of benzidine. The present author finds that this is the case only when the blue substance has been obtained under circumstances where the chromic acid has not had full scope for oxidation (viz., cold dilute nearly neutral solutions), and that even then the amount of benzidine recovered is an insignificant fraction of that originally taken. On the other hand, when a benzidine hydrochloride solution is slowly added to bichromate solution at about 40°, and after 20 minutes or so, the blue paste is decomposed, in the liquid, with caustic soda, the resultant product is wholly a chestnut-brown base, free from benzidine.

The investigation both of the original blue substance and of the base is rendered very difficult by their reactivity, but so far as the author can see the base appears to be a hydrated form of diphenoquinonediimine, of which the anhydrous form was obtained by Willstätter and Kalb (*Berich.*, 1905,

p. 1232) by oxidising an ethereal solution of benzidine with lead peroxide. The constitution of the hydrated base must be either



of which the former is the more probable.

The blue chromate and ferricyanide are very beautiful substances, bearing an obvious analogy in lustre and felted crystallisation to the similarly-constituted bodies cœrulignone and tetraminodiphenoquinone. Substances of this class give an intense coloration, even in traces, to concentrated sulphuric acid, and the base of "benzidine chromate," diphenoquinonediimine, gives an intense crimson shade exactly the same as that given by a specimen prepared by Willstätter's method. On the other hand, the original blue chromate gives only an orange colour, probably owing to the CrO_3 interfering with the reaction.

As an example of the difficulties attached to the investigation, it may be mentioned that the blue substance can scarcely be dried without undergoing some degree of internal oxidation, with the result that the base prepared from it is always contaminated with the lower oxides of chromium, as well as an intractable black organic substance which resists reduction. The base itself alters on dehydration and is decomposed in the warm by the hydrolytic solvents, whilst it is only sparingly soluble in the indifferent ones. In addition, the proportion of combined CrO_3 is somewhat variable in different preparations. In fact a considerable portion of the work on this substance deals with its alteration-products rather than with itself.

Some preliminary work, done before its behaviour was fully realised, may be first mentioned. By dissolving benzidine in excess of very dilute acetic acid at 35° and adding chromate in excess (but not so as to render alkaline) and leaving overnight, a yield of 154 per cent. of the blue substance washed out with water, alcohol, and ether and dried *in vacuo* was obtained. Analysis of this product gave C = 49·6 per cent., H = 4·85 per cent., Cr = 14·7 per cent., N (Kjeldahl) 8·75 and 9·15 per cent.

Diphenoquinonediimine chromate $C_{12}H_{12}N_2CrO_4$ would contain 48·0 per cent. carbon, 4·0 per cent. hydrogen, 9·3 per cent. nitrogen, and 17·3 per cent. chromium, and the theoretical yield is 163 per cent., so that for some obscure reason the product in this case contained only about $\frac{5}{6}$ of the normal proportion of CrO_3. On treating the dried specimen with alkali, about $\frac{1}{8}$ of the benzidine originally taken was recovered from it. At the low temperature of preparation it may therefore possibly have contained a small quantity of true benzidine chromate $C_{12}H_{14}N_2CrO_4$. Under the circumstances direct calculation of a formula from the analysis may be

somewhat fallacious. However, the formula $C_{12}H_{12}N_2O + \frac{3}{4}H_2CrO_4$ agrees fairly well, requiring C = 49·9, H = 4·7, Cr = 13·5, N = 9·7 per cent. The supposition indeed might be made that the diimine has four times the normal molecular weight, its constituents being so arranged as to give only six amino groups, *i.e.*, $C_{48}H_{48}O_4N_8 + 3H_2CrO_4$. In one preparation, however, where dilute hydrochloric and only two molecular proportions of $K_2Cr_2O_7$ were used, the product contained 17·0 per cent. chromium, in agreement with normal diphenoquinonediimine chromate. Again, when a fair amount of mineral acid and considerable excess of CrO_3 are used a different substance is obtained. This forms olive-green, practically black, felted needles with a faint reddish lustre, and is apparently a simple sesquichromate of diphenoquinonediimine. The same substance is obtained more certainly by oxidising benzidine in cold hydrochloric acid solution with permanganate (about 15 cc. N solution per gram) to the deep-orange diimine hydrochloride and then precipitating with CrO_3 solution. The chromium-content, however, varies between 20 and 24 per cent.

A special preparation of this dark substance was made by treating benzidine in HCl solution with dilute H_2O_2 and then with CrO_3 in excess (H_2O_2 alone has no action in the cold, though in absence of mineral acid a white peroxide of benzidine has been obtained in long white needles). The crystalline product had a bronze lustre and contained no chlorine. After prolonged drying at 50° C., 0·4854 gm. gave 0·7220 CO_2 and 0·1887 H_2O, also 0·1472 Cr_2O_3. Kjeldahl nitrogen was 6·1 per cent., but the method is probably unsuitable. Found C = 40·6, H = 4·3, Cr = 20·7, N = 6·1. $C_{12}H_{10}N_2 + 1\frac{1}{2}H_2CrO_4$ requires C = 40·1, H = 3·6, N = 7·8, Cr = 21·7 per cent. The base of this preparation was extracted with acetone, precipitated by water, and boiled out with excess of the latter to remove a little benzidine. This treatment evidently caused it to lose nitrogen, as it melted indistinctly at 190° C. (the diimine melts at about 270°). It was nevertheless analysed, as it had appeared to be uniform. 0·2187 gave 0·6917 CO_2 and 0·1118 H_2O : 0·1351 used 5·62 N/5 acid. Found C = 79·9, H = 5·7, N = 11·7 and 12·3 per cent. $C_{12}H_{10}N_2$ requires C = 79·1, H = 5·5, N = 15·4.

An attempt to synthesise a quinhydronic compound of diphenoquinone and benzidine (which would agree with these figures) gave an olive crystalline compound which gives an olive to blue coloration with H_2SO_4. The present compound is therefore not a benzidine-quinhydrone.

Barzilowsky's "Benzidine Ferricyanide."—Potassium ferricyanide does not oxidise benzidine in mineral-acid solution, though it does so in neutral or acetic acid solution. The blue product is, however, amorphous. A crystalline preparation is easily obtained by first oxidising with permanganate and then adding K_3Fcy (using acid enough to keep up manganese

ferrocyanide). K_4Fcy, after $KMnO_4$ not in excess, gives an amorphous dull-grey compound, so that Barzilowsky's blue substance is a ferricyanide. On treatment with ammonia internal reduction occurs and a little benzidine and ferrocyanide appear in the aqueous extract, and the crude diimine base is left insoluble. The blue compound gives an orange colour with H_2SO_4 (the base, crimson as usual) and is apparently $2C_{12}H_{10}N_2 + H_3FeCy_6$. Found Fe = 8·6 per cent. instead of 9·7 per cent. When reduced with $KHSO_3$, benzidine sulphate was the only product.

The base from Barzilowsky's compound was boiled out with water, dissolved in much alcohol, reprecipitated, and again dried at 100°, and was nearly free from ash. 0·1232 gave 0·3470 CO_2 and 0·0690 H_2O; also 0·0020 Fe_2O_3. 0·239 used 11·3 cc. N/5 HCl. Allowing 0·0022 for $HFeO_2$, this gives C = 78·3, H = 6·3, N = 13·5. The substance melted at 255–260, and behaved exactly as Willstätter's diimine does.

The following experiments show that despite the poor analytical figures for the dried substances, the blue compounds are really salts of diphenoquinone-diimine :—

(1) *Quantitative Reduction :* 1 gram benzidine in HCl at 40° (in about 1 litre water) was treated with 2·5 grams bichromate and the blue paste digested for 20 minutes (when all benzidine is oxidised). Stannous chloride was added, and when the mixture became clear the tin was removed by H_2S. The tin precipitate was extracted with soda and alcohol to recover adherent benzidine and the extract added to the rest. Sodium sulphate was added in excess and the benzidine-sulphate allowed to crystallise out during two days. 1·334 gram was obtained. The mother liquor was taken to small bulk and acetylated, giving 0·0825 gram of white diacetylbenzidine of mp. 310° (uncorr.). The acetylation liquor still contained a trace of benzidine recognisable with CrO_3. Nevertheless, 93 per cent. of the benzidine taken was recovered as sulphate and acetylderivative, thus leaving practically no possibility of there being another reduction-product. Similarly, when the diimine hydrochloride is reduced by SO_2 the only product isolated was benzidine sulphate. On the other hand, when the *dried* blue substance is reduced only a comparatively small quantity of benzidine is obtained and most of the substance remains insoluble.

(2) *Isolation of Diimine.*—In order to avoid decomposing the diimine, the blue paste obtained as described above, or Barzilowsky's compound, was decomposed *in situ* without filtration with excess of dilute caustic soda, and filtered off, using the pump, and thoroughly washed out with cold water. (Owing to the slimy character of the product this operation takes many hours.) It was then dried for a week over H_2SO_4 *in vacuo* and the product pulverised and extracted with a mixture of ether and CS_2

to remove anything soluble. After this an extract made with warm benzene yielded on evaporation at a low temperature about ¼ gram of deep red-orange crystals with violet lustre melting at 255° to 265°, and apparently identical with Willstätter's anhydrous diimine. This specimen was not reducible with SO_2 or sulphite (which blackens it), but easily by $SnCl_2$ to benzidine.

The diimine base can apparently also be got direct from benzidine by heating its solution in acetic acid with H_2O_2, but a satisfactory specimen for analysis was not obtainable by this method. The solution of its hydrochloride made by the permanganate method when diluted or nearly neutralised turns deep indigo-blue, but it is impossible, on account of its extraordinary instability, to say whether this is due to formation of a basic salt or to reduction to a quinhydronic compound. Similar fugitive blue basic compounds are obtained (1) by insolation of an ethereal solution of benzidine (2) in the H_2O_2 + benzidine tests for blood and peroxydases, (3) in the author's test for HCN with benzidine and cupric acetate, and generally in the oxidation of nearly neutral solutions of benzidine and its derivatives.

In the course of the author's earlier work five years ago on this subject, he obtained in the sulphite-reduction of these compounds are insoluble, infusible, glistening white substance which he supposed to be benzidine sulphonic acid from its solubility in dilute ammonia and its quantitative behaviour on titration. This is now found to be a basic benzidine sulphate $C_{12}H_{12}N_2 + \frac{1}{2}H_2SO_4$. Found N = 12·3 per cent., S from 7 to 10 per cent. in different specimens; mol. wt. by back titration found 256 (assumed monobasic).

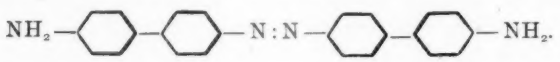
Normal benzidine-sulphate crystallised from boiling dil. HCl is as lustrous as silver, forming a network of pseudo-hexagonal plates with extinction 20½° to right. Benzidine picrate forms long densely-felted yellow needles which blacken at 190°.

True benzidine chromate cannot be obtained in stable form. K_2CrO_4 has no action on aqueous benzidine, but in presence of a *trace* of acid in very cold solution a pale green precipitate, rapidly turning blue, results. Normal benzidine dihydrochloride gives the blue substance with K_2CrO_4 at once.

"Benzidine chromate" is a basic type of salt and is very sensitive to mineral acids which in small quantities darken it, whilst it dissolves easily in excess of cold dilute acid to the normal orange diphenoquinone-diimine salt. The nitrate can be easily isolated in crystalline form either by suitable oxidation of a cold saturated benzidine nitrate solution, or by dissolving the blue "chromate" in dil. HCl at 40° and adding 30 per cent. HNO_3. It is fairly easily soluble in pure water to an intense orange solution, which turns green and eventually violet-brown on great dilution.

The solution of the chromate in acid also turns green on dilution, but this is due to simple re-precipitation of the blue substance in fine division.

The dirty-violet solution, obtained on allowing the diimine salt solutions to stand, gives with alkali a dark violet base which is an aminoazo dye. The substance has not yet been properly investigated, but in all probability it is the dimolecular polymer of the diimine suspected by Willstätter, viz., azodixenylamine or diamino-azobisdiphenyl :—



It can be made direct from benzidine acetate and ammonium persulphate or by insolating a mixture of benzidine and cupric acetates. Its ferrocyanide is crystalline, almost black with bronze lustre, 0·3349 gave 0·0286 Fe_2O_3 – Fe = 5·98 . $2C_{24}H_{20}N_4 + H_4Fcy$ requires 5·92 per cent. The HCl-salt of this dye appears to be the product of the action of aqueous $FeCl_3$ on *neutral* benzidine solution: very dark violet substance sparingly soluble in water. Found 7·1 per cent. Cl. The dye is quite different from Willstätter's diimine, and gives with H_2SO_4 a very dark olive coloration.

One remarkable observation has recently been made, which throws doubt on the possibility of the existence of the free diimine. When a freshly-prepared solution of the diimine nitrate is made faintly alkaline with ammonia, the brown precipitate obtained gives, immediately after washing, a yellowish olive coloration with H_2SO_4; but on treatment with boiling water it deepens in colour and then gives the normal crimson shade. Whilst it is possible that the fresh substance is merely a highly hydrated diimine, it is more likely that it is the true diimine and that the substance giving the crimson colour (Willstätter's compound) is an isomeric or polymeric variety. It might be a simpler explanation of the whole subject to suppose that the yellow nitrate belongs to the true diimine series, whereas the blue solution formed by diluting it, and also the blue chromate and ferricyanide, are quinhydronic in character, intermediate between benzidine and the diimine. The analytical figures agree with either assumption.

Two other substances of the class have been made by adding CrO_3 to solutions of salts of 5-5′ dibromo-3-3′ tolidine and 3-3′ dibromobenzidine respectively. Both resemble indigo but are amorphous, and their analytical figures were unsatisfactory. The first gave Br = 23·3, Cr = 17·05 per cent., and the second, Br = 37·2, Cr = 5·2 per cent.

PRELIMINARY NOTE ON THE METEORITES IN THE BLOEMFONTEIN MUSEUM.

By W. A. Douglas Rudge, M.A., Bloemfontein.

(Read, March 15, 1911.)

(With Plates V., VI., VII., and Text Figures.)

The Bloemfontein Museum contains three meteoric specimens, and as they have not been previously studied, it seemed worth while to undertake an examination of them.

Two of them are fragments of the same fall, and the other one is of quite a different character.

The first two are portions of a fall which occurred at Kroonstadt in the Orange River Colony in 1877 (November 11th), whilst the other fell at Zeekoegat Farm, Winburg, in 1881, but the precise date cannot be ascertained, and in the following account they will be referred to as the Kroonstadt and Winburg specimens respectively.

Kroonstadt Meteorite.

This consists of two fragments, weighing respectively 1,382 grammes and 663 grammes, the external appearance of which is well shown by Figs. 1 and 2 for the larger, and 3 and 4 for the smaller. Both these stones are portions of a larger one, as an examination of different sides shows, the surface of the one side being quite different from that of the other. Fig. 3 represents probably the original surface of the meteorite, Fig. 4 is that of a fractured surface. The black crust on A is perceptibly thicker than that on B.

The external and internal appearance of the two specimens are so similar that one has no hesitation in ascribing it to the same origin.

The larger of the two specimens had been chipped so that a portion of the crust had been removed, and it appeared to consist of a greyish ground mass with brown patches disseminated throughout. Many shining specks of nickel iron and troilite could be seen by the microscope, and the stone was markedly magnetic and showed slight polarity. Attempts were made to obtain sections, but the stone was too hard and at the same time so loosely held together that this was not possible. The exposed surface was

then ground flat and polished, and the structure was then very clearly seen (Fig. 5).

Here the masses of nickel iron stand out sharply from the ground mass, their shapes being well represented by those in the centre of the Fig. These masses could be dug out with some difficulty and then appeared to be tough malleable particles, having all the physical properties of an alloy of iron and nickel. The stone was exceedingly hard except where the metallic particles were found, and this made it difficult to polish satisfactorily. "Chondri" could not be definitely detected.

FIG. 1. Magnification, $\frac{5}{8}$. Actual height, 11 cm.

The specific gravity was found in the usual way and was ascertained to be—

Larger fragment	3·536
Smaller fragment	3·551

Both specimens were porous, as was seen during the specific gravity determination. The first specimen weighed in air 1382·2, and in water 989·5, but the latter weight gradually increased to 991·4 after one hour's immersion, so that water to the extent of 1·9 grammes had been absorbed.

The specific gravity given above was calculated from the loss in weight after one hour's immersion.

FIG. 2. Magnification, $\frac{1}{3}$. Actual height, 11 cm.

FIG. 3. $\times \frac{1}{2}$.

The second specimen weighed 663 in air, 476·3 in water shortly after the immersion, but after thirty minutes the weight was 475·6. The meteorite was easily crushed, but could not be reduced to a fine powder

on account of the metallic particles. These particles were readily separated from the other matter by means of a magnet, and formed more than half of the whole mass. The metallic portion is partially soluble in

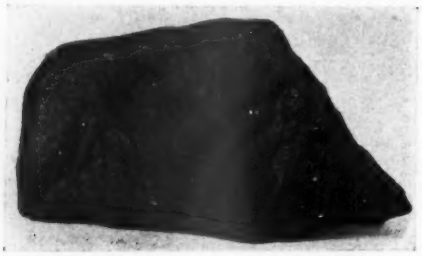


Fig. 4. × ½.

dilute sulphuric acid, and completely soluble in aqua regia. Hydrochloric acid attacked the powder with evolution of sulphuretted hydrogen owing

Fig. 5. Magnification, 10 diameters.

to decomposition of the troilite. After digestion for two days with hydrochloric acid and boiling off the sulphuretted hydrogen, the residue was dissolved in aqua regia. Sulphuric acid was now found in the solution, so

that the presence of iron pyrites or some other sulphide may be inferred. Qualitative analysis showed the presence of iron, nickel, aluminium, calcium, silicon, and sulphur, and traces of manganese, but no carbonic acid. An exhaustive analysis has not yet been made.

The iron, nickel, and insoluble matter were determined quantitatively. The meteorite was crushed as far as possible in a steel mortar, the tough metallic particle separated by a magnet, and the residue ground further in an agate mortar. The two portions were mixed and weighed. The material was heated upon a water bath with aqua regia until no further action occurred, evaporated three times to dryness with hydrochloric acid, the insoluble matter filtered off, dried, ignited, and weighed. The soluble portion was evaporated with sulphuric acid, to convert into sulphates and made up to a definite volume. In one portion the iron was found by precipitation with ammonia and conversion into ferric oxide, and in another portion the iron was reduced to the ferrous state and titrated with standard permanganate. The nickel was estimated in a portion from which the iron had been removed, by the process given in Crooke's Select Methods.

The chief constituents present are :—

Insoluble matter	54·68
Iron	30·38
Nickel	13·21

As a section could not be obtained, it is difficult to specify exactly the minerals present, save the iron-nickel alloy, troilite, pyrites, and perhaps asmanite, but the siliceous matter was only slightly soluble in sodium carbonate. The general structure seems to be one of aggregation of small more or less rounded particles round a skeleton of the iron-nickel alloy. The non-metallic grains were never complete crystals. On examination in polarised light a few grains of what appeared to be a much-twinned felspar were seen, and brownish grains which showed brilliant colours.

The Winburg Meteorite.

This is a very remarkable specimen of an iron meteorite. As far as can be gathered, it was seen to fall by some natives working on the farm of Zeekoegat in 1881, and reported by them to Mr. Schnehage, the owner of the farm. It was removed to the farmyard and remained there for some years, and was finally deposited in the Bloemfontein National Museum.

As regards its external appearance, it is nearly black and plentifully covered with "thumb" markings, but different surfaces are quite distinct, as the photographs show.

Figs. 6 and 7 are taken from opposite sides. The surface is covered

over with well-impressed marks which, in places, show some signs of exfoliation due to surface oxidation, and similar appearances are met with on the top and bottom. Fig. 7 indicates very clearly that the meteorite must have been a portion of a larger mass, and the sharp line at the top,

Fig. 8. Actual size. 23 cm. across longest diameter.

and the irregular line running across the surface look very much as though the mass had been torn violently from another piece. The extreme length is 38 cm., and thickness 23 cm., and the weight about 50 kilogrammes. The whole mass is very soft externally, and can be easily indented with a blow of a hammer, and can even be cut with a knife, but there are portions of great hardness.

A section was made across the meteorite, and the exposed surfaces polished. When this was done a number of veins of a much more lustrous metal were seen embedded in the mass of iron, and standing out clearly on account of their brightness. One surface was not further treated, and the other "etched" with dilute nitric acid.

These veins are not uniform, but can be seen with a moderate magnifying power to consist of a metallic network enclosing black particles. Fig. 8 shows the surface polished, but not etched. Fig. 9

FIG. 9. 21 cm. across longest diameter.

shows the surface after etching, and about $\frac{2}{3}$ of the actual size. The area of the polished surface is about 230 sq. cm. In this Fig. the Widmanstatten lines are seen developed, and also the network of the veins. Fig. 9 in Plate VI. shows the lines after etching with stronger acid.

Fig. 10 shows a portion of the surface under a magnificature of 5 diameters. The remarkable triangular arrangement of the interlocking crystals is well shown here; the details of this will be referred to later. The black matter running through the network of the veins is also clearly

seen. Small portions of the surface were submitted to higher magnification, and Figs. 11, 12 and 13 are the results. In Fig. 11 is shown a complete crystal, which had a very bright border line, the edges glistening like silver beads under reflected light. The magnification in this case is about 20. Fig. 12 shows another portion; the different reflecting powers of the various constituents enable the individual crystals to stand out clearly from each other.

Figs. 13 and 14 show portions of one of the veins magnified 20 diameters; the carbonaceous matter filling the network is here well defined. At low magnification the etched figures are not so well defined as is usually the case with meteoric irons. The reason for this will be clear

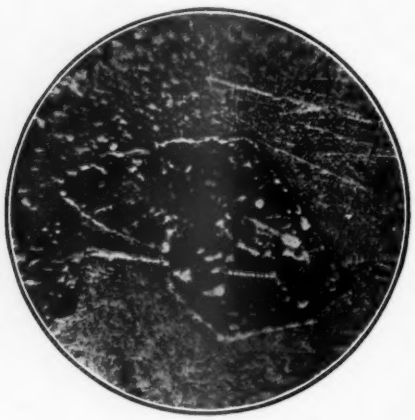


Fig. 11. Magnification, 20 diameters.

when the chemical composition has been explained. The striking feature of the structure seemed to be the presence of the veins composed of a material differing considerably in composition from that of the general mass.

The meteorite is very readily attacked by acids, as might be expected from its purely metallic nature. It dissolves completely in aqua regia, with the exception of a small quantity of earthy matter, which I believe is located only in the veins. Dilute sulphuric also attacked it, but in this case there is an insoluble residue composed of carbon, and also crystals of an alloy of iron and nickel. Practically nothing but iron goes into solution in dilute sulphuric acid, the iron-nickel alloy being insoluble, but dissolving readily in aqua regia.

A small piece of the meteorite with a vein running through it was

cut off and digested in dilute sulphuric acid (1/20) for two days. The specimen was arranged upon a perforated disc in a funnel, so that the ferrous sulphate formed by solution of the iron could be drained away without disturbing the residue. When this was done a beautiful skeleton crystalline mass of the alloy remained behind. The interstices were filled with carbon in an amorphous and powdery form. The structure was so fragile that the slightest jar given to the funnel caused it to fall to pieces. A photograph of the debris is shown in Fig. 14, Plate VII. It looks like the remains of an octahedral crystal. One has hopes, with more careful treatment, to obtain one of these skeleton crystals.

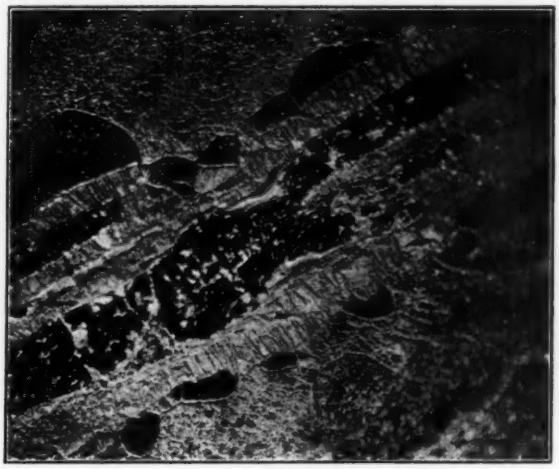


Fig. 13. Magnification, 20 diameters.

The residue usually left behind by solution in dilute sulphuric acid consists of carbon containing siliceous matter and triangular flakes of iron nickel, evidently portions of larger crystalline masses, as Figs. 15, 16, and 17 will show. Some of the flakes attain a length of more than a centimeter, and have bright glistening surfaces. Fig. 15 is a shadow photograph. There is evidently a tendency to cleave into small triangular pieces. Occasionally "cross hatchings" are seen, as in Fig. 10*a*, but as a rule they are not present. The whole mass is distinctly magnetic, having a number of poles which we easily found with a small compass, and magnetic susceptibility was retained by the crystals up to a red heat. The meteorite is thus composed of a mixture of pure iron and iron-nickel

alloy, the latter being easily separated. The black residue left with the alloy consisted of carbon—perhaps some hydrocarbon. It ignited readily, and in some cases burnt out with a luminous flame. It dissolved with the alloy on heating in aqua regia.

After solution of the crystalline mass and the carbon in aqua regia, a small residue was left, consisting of microscopic grains of brown or white material. The grains showed brilliant polarisation colours, and appeared to consist of silica. Very careful search was made to ascertain

FIG. 14. Magnification, 20 diameters.

whether any diamonds were present, but no positive evidence was obtained. There were, however, a few transparent particles, more or less hexagonal in form, in which a microlith of a pink mineral was found. The particle had no influence on polarised light, but the pink microlith had, having an extinction angle of about 15°.

CHEMICAL COMPOSITION.

Analyses were made (*a*) upon the meteorite as a whole, (*b*) upon the portion soluble in dilute sulphuric acid, and (*c*) upon the crystals of the alloy.

(*a*) Some cuttings weighing about 1 gramme were dissolved in aqua regia, evaporated to dryness with sulphuric acid, the ferric salt reduced, and the amount of iron found by titration with per-

manganate. The amount found varied between 94 and 95 per cent.

(*b*) The cuttings were digested with dilute sulphuric acid, and the amount of iron found by permanganate. The average was 92·32 per cent.

(*c*) A weighed portion of the crystals of the iron-nickel alloy were dissolved in aqua regia, the iron determined in one portion of the solution and the nickel in another. The mean of several analyses gave an extra 2·35 of iron, and 2·00 per cent. for the nickel, calculated upon the meteorite as a whole.

The composition of the meteorite as regards its main constituents may thus be summarised:—

Iron soluble in dilute sulphuric acid	92·32
Iron in crystals	2·35
Nickel in crystals	2·00
Carbon and earthy matter	0·3

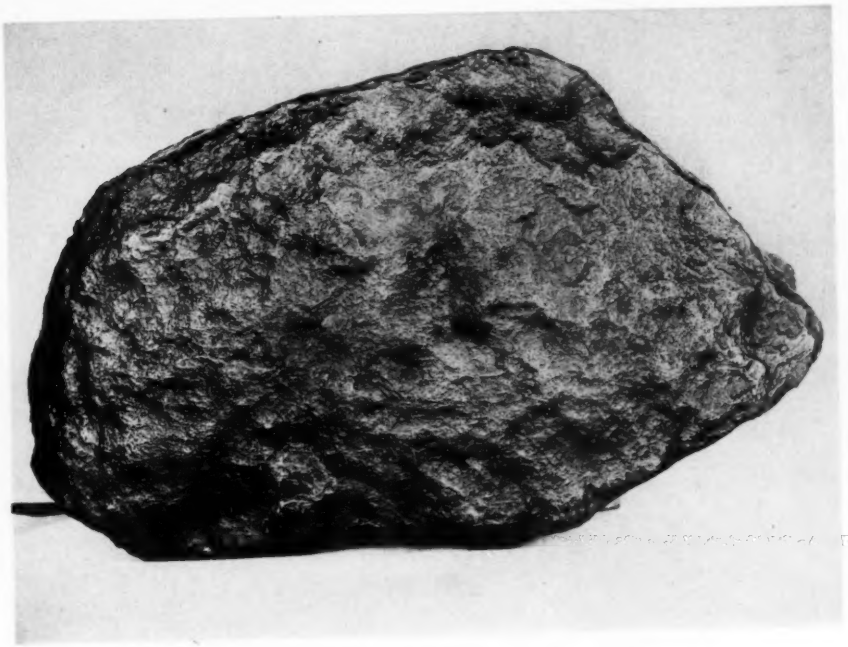
The meteorite, then, appears to be a mass composed of crystals of iron-nickel alloy embedded in a matrix of iron, with only a very small amount of nickel in the general mass.

The total percentage of nickel is small, and most of it is concentrated in the vein of the alloy running through the mass.*

My thanks are due to the Committee of the Bloemfontein Natural Museum for permission to examine the structure of the meteorite.

Physical Laboratory, University College,
Bloemfontein.

* A complete chemical examination has not yet been made.



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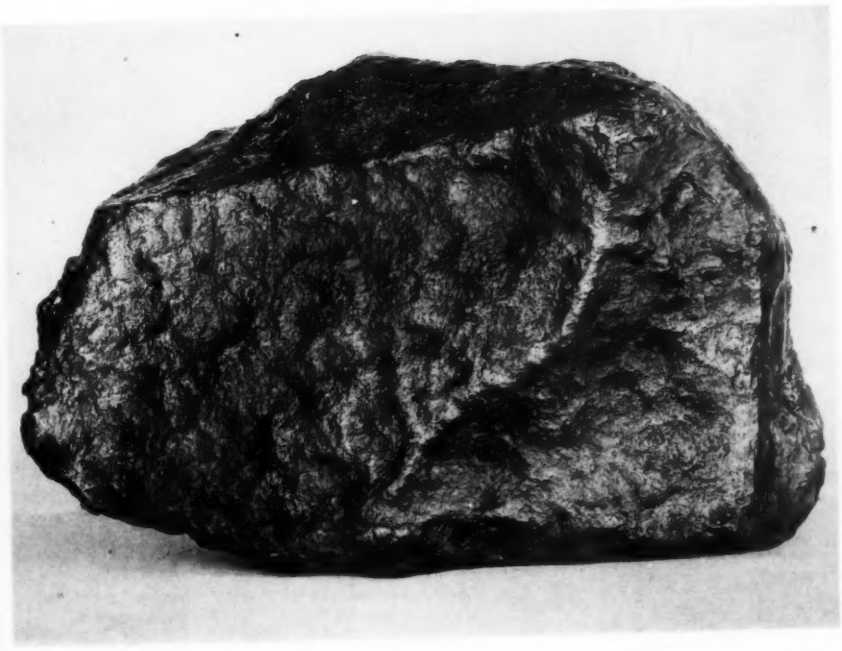

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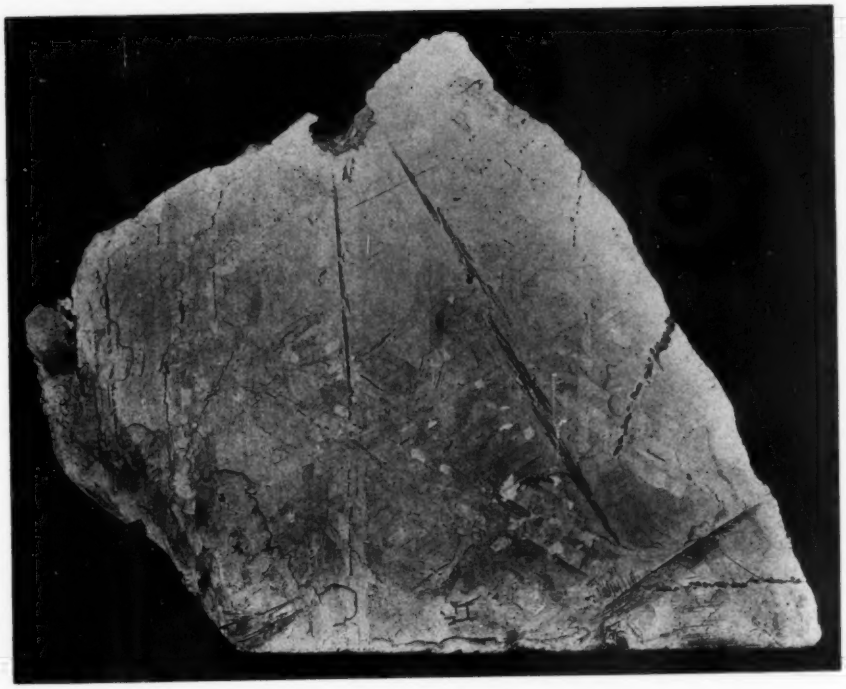

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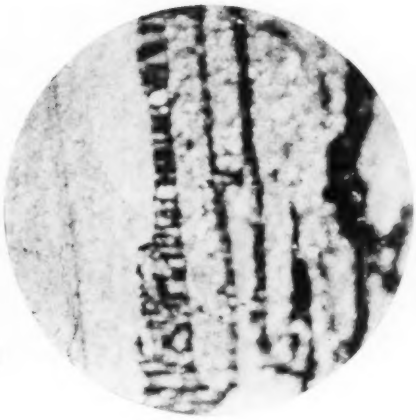

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THE FUNERAL CEREMONIES OF THE HOTTENTOTS.

By C. Leo. Biden and Rev. H. Kling.

(Communicated by L. Peringuey, read March 15, 1911.)

The Hottentots have their medical men who treat patients during illness. Like most South African tribes, witchcraft is practised by these men, and the sick are told that their enemies, bad relatives, and bad neighbours are the cause of the illness. The medicine-man prepares medicine from herbs, bark, shells of ostrich eggs, and even out of the dung of certain animals and the urine of rock-rabbits (*Procavia capensis*). An incision is made in the skin of the afflicted person by means of a calf's horn, and the medicine is injected in the scarified part, the patient being told to believe in various omens. In the event of death following, the medicine-man attributes the disaster to the bad influence of certain parties—actually naming the persons whom he thinks are concerned. Formerly these "responsible" persons were put to death, but since the Hottentots have become more civilised there is no imposition on such people, but the inevitable result is that such a practice causes much hatred and personal feeling among the Hottentots. The relatives of the deceased are told to comfort themselves in apathy—as a matter of fact they are extremely apathetic in their general life. The monotonous and poor country in which they live gives no incentive for development, and their dull and uninspiring life is typical of the weirdness of the country. Immediately after the death they prepare for the funeral. The body is sewn up in a skin or matting (at present in old bags, if obtainable), and a small amount of salt is placed on the chest of the body—a reason given for this is to prevent the body from decomposing! There are no recognised graveyards or general burial-grounds, but a spot is selected and a hole is dug in the sand by means of a Gemsbok (*Oryx gazella*) horn and a roughly made wooden shovel. The body is carried to the grave by the deceased's relatives and friends, and the womenfolk sit round about. One woman is appointed to approach the body, and ask a relative of the deceased whether deceased gave drink to others when alive—this means whether he was a good person. Whereupon all the

women reply "da" (yes), and the deceased is praised even if there is no cause why he should be praised. All the women arise and walk towards the grave and sprinkle buchu-leaves (*Barosma crenulata*) on the body. These buchu-leaves, together with a skin of a rock-rabbit, are kept in a tortoise-shell, which is always worn at the belt by the women. The buchu-leaves are obtained from the mountains along the sea-coast. The body is then lowered down into the grave and placed in a sitting posture in a cave hollowed out left or right of the bottom of the grave. Large flat stones are placed in such a position that no ground can fall on the body. The grave is then filled in, and the Gemsbok horn and shovel are left on the grave in an upright position. In former years the Hottentots in some instances adopted the funeral ceremonies of the Damaras and Ovambos. In the case of a married man dying, the backbone of the deceased's wife was broken; and in the case of a woman, that of a slave; and the unfortunate victim was buried in its dying agony alongside the deceased. After the funeral, strangely enough, a dance is held, and the deceased's cattle and sheep are slaughtered, and festivities are indulged in all through the night. The music men (eight) have short reeds that are peculiarly pitched so as to emit some kind of tune. For a few weeks the male relatives of the deceased go to the grave every morning before sunrise, quite naked, and pray to the "thās" (ghost). The idea of visiting the grave in a nude state is that the ghost cannot catch them! They talk to the grave and sprinkle buchu-leaves on it, and beseech the ghost to do them no harm and to leave them undisturbed at night-time. After a month or so they suppose that the ghost has left the grave and has entered an animal called by them "Thās jackals."* The Hottentots say that this animal has never been caught, and that it could only be killed by a silver bullet!† According to them this "Thās jackals" leaves its shelter at night-time only, and glides along the ground like a shadow, and that this animal is the house of the ghosts of the deceased people! It has also been described by them as having a very large head; but as no one has ever actually seen it, the description cannot be given. They believe it is very strong and cannot die—and no attempt has been made to kill it. This, of course, may be mere superstition; but at the same time it goes to show that the Hottentots do actually believe in the transmigration of souls! When the animal makes a noise "thā . . thā . . thā . ." (at night), the people cover themselves with their karosses; and if the Hottentots happen to

* This word jackals was of course introduced by the Dutch, but borrowed from the Turkish "tchakāl," or the Persian "chaghāl."

† A belief distinctly traceable to contact with the early Dutch colonists, and appropriated by the Hottentots.

be at their evening meal when this noise is heard, each throws some food backwards to satisfy the "Thās jackals," that no harm may come to them! The cry of this animal is said to be much louder than that of any other nocturnal animals.

A peculiarity of the Hottentots in doing homage to their dead is what they call "heidje eibib." In the event of a grave being close to a road where the Hottentots continually pass to and fro, the wayfarers throw a stone on to the mound when passing by. This is a sign of honour to the deceased, and this duty is strictly observed where there are graves of ancestors of the Hottentots. There is a large "heidje eibib" at Stygerkraal, near O'okiep; the Hottentots say that this grave is that of one of their great-grandfathers who originally came from another country.

PHOTOGRAPHY AN AID TO ASTRONOMY.

PRESIDENTIAL ADDRESS BY S. S. HOUGH, M.A., F.R.S.

(Read April 19, 1911.)

The reports you have just received relate to the administrative aspects of the work of our Society during the year, and no more fitting subject could be found for an address from the Chair than a similar summary of the annual scientific output. Unfortunately, if such a duty were thrown on your president, I fear that with such a vast range of subjects to review, as indicated even by the titles alone of the papers with which we have had to deal, the task would be overwhelming, and I have felt it necessary to adopt the alternative course of limiting my attention to a branch of scientific investigation in which I could but modestly hope that my own experiences would enable me to speak with some pretentions to authority.

In my address last year I endeavoured to put before you some of the problems which confronted the astronomer and to illustrate the reasons why the most refined methods of physical measurement available were necessary in order to secure data for the solution of such problems To-day I propose to deal rather with the methods in use and the progress which has been and is being made in securing the necessary data for discussion, and in particular to sketch to you the advances which have been rendered possible through the introduction of photography as an aid.

Now-a-days when portable hand-cameras are accessible to every one, when photographs can be taken by the mere expedient of pressing a button, leaving the manufacturers who supply the material to "do all the rest" at a trifling cost, or when even the processes of development can be performed by an inexperienced operator without the aid of any more elaborate equipment than a supply of fresh water, one is apt to forget how recent is the development of photography, not merely as a science or art in itself, but still more as a useful adjunct to almost every other branch of scientific investigation.

To appreciate the uses of photography try and imagine if you can

a state of existence deprived of the sense of sight, not only in the individual but throughout the human race. The phenomenon of light could doubtless still exist and even be capable of exerting certain physiological action; but this phenomenon is one with which we are primarily cognisant through the direct physiological action on the optical nerves and without which the intercourse of the individual with the external world is perhaps limited by the further senses of "sound," "touch," "smell," and "taste." All these senses, even including the first, are brought into operation only by closely adjacent surroundings, whereas the additional sense of sight, apart from its use as a means of communication between individuals, is the sole remaining sense by which we can obtain information regarding unexplored and otherwise inaccessible regions.

I venture to doubt whether under such conditions the human intellect would have risen to such primary conceptions as that of a "point" and a "line," let alone a "straight line," and whether even the most primitive of the sciences, that of geometry, could have originated, though perhaps a sense of geometrical form might have been developed through the touch.

Be that as it may, however, it is perhaps not too much to say that our knowledge of the extra-terrestrial universe has at least until recently been derived solely through the medium of those ethereal vibrations which we call light, to which our eyes respond, thus communicating with the brain; and though this physical phenomenon might conceivably have existed apart from the existence of human or other eyes, its existence could scarcely have been recognised and the science of astronomy which deals primarily with extra-terrestrial phenomena could hardly have been.

Thus it is that the development of this science has been largely concurrent with the development of those instruments by which the optical efficiency of the eye has been increased.

The earliest observations were made with the unaided eye, the results which have come down to us being duly recorded either in the form of descriptions or drawings, or even in some cases by more or less exact measurements. The introduction of the telescope not only immediately opened up fields of vision previously inaccessible, but facilitated in a very marked degree the precision with which measurements could be made, and for about three centuries the telescope has been used as a direct aid to the visual organ. It is improbable that this method of observation will ever be superseded, but there is to-day a growing tendency to replace the human eye at the end of the telescope by the photographic camera.

The advantages of the method are twofold.

(1) Objects which are too faint to be seen with the eye may yet be photographed by a sufficient extension of the time of exposure, and our power of penetrating the confines of space is thereby increased.

(2) The photographs themselves form a permanent record of what is seen more reliable than can be obtained from any drawing or description executed at the hands of man.

The early applications of the art of photography to astronomy related to the subject from its descriptive aspect rather than to those branches of the science which depend on exact measurement. With the aid of reflecting telescopes of large aperture it was found possible to delineate with certainty the forms of vast nebulæ, so as to establish with great nicety the extension of their convolutions into regions where to the eye alone their traces were quite invisible, even with the aid of powerful telescopes. But fascinating as these photographs are in aspect, valuable as they are as early records, and suggestive as they are with regard to the cosmical significance of the objects photographed, it can hardly be maintained that they have so far been prolific in scientific results. Such phenomena as the wonderful spiral forms assumed by many of the nebulæ, though proved to be far more common than was previously realised, remain as obscure as ever in their origin.

In making this statement I do not wish to underrate the work of the earlier pioneers in astronomical photography. They have developed methods which we continue to use and have but little to improve on, and they are not to be blamed if the full value of their work has not been attained in their own generation. Visual work had already been carried so far that the extended vision afforded by photography could hardly have been expected to lead instantaneously to any new and startling phenomenon which should revolutionise existing ideas of the extra-terrestrial universe. It is only as time lapses and we are able to study the changes which are taking place since these photographs have been secured—changes which as a rule take place so exceedingly slowly as not yet to be fully established—that the full advantage of the new method over the old will be realised.

The earliest attempt at the photography of celestial objects seems to date back as far as the year 1840, when photographs of the moon were obtained by daguerrotype processes, but beyond its use for pictorial presentation—to which perhaps I might add the daily photographic record of the sun's surface instituted at Greenwich in 1873, and unsuccessful attempts by Pritchard at the instigation of Warren de la Rue to utilise it for the determination of the constant of nutation—for a long time it seems to have been regarded with suspicion for purposes requiring the use of exact measurements. While photography might supplant the astronomical draughtsman, its limitations were in other respects similar to those affecting the draughtsman's art and skill. It is its uses in connection with precise measurement with which I propose chiefly to deal to-night; not that I wish to underrate the importance of other applications,

but that I prefer rather to confine myself to those branches with which I have myself been more directly concerned.

The year 1882 saw the first introduction of astronomical photography into the Cape Observatory. No special appliances for the purpose were at the time included in its equipment, but the unexpected appearance of the great comet of that year demanded that an effort should be made to secure a representation of this comet by photographic methods which had been vigorously developed elsewhere for such purposes. Accordingly the services of a local photographer were secured, and in order to obtain a sufficiently long exposure to bring out the faint detail of the comet's tail, his camera was attached to one of the equatorial telescopes of the Observatory so that it might partake of the motion imparted to the telescope and thus be kept pointed on the comet for a prolonged interval.

Valuable photographs showing much detail of the structure of the comet were obtained, but the feature to which particular attention was directed was the large number of stars, some of them extremely faint which, besides the comet, were all duly recorded on the plate. Moreover, the sharpness of the photographic images suggested that they would permit of very accurate measurement, and that, if only similar definition could be obtained in photographs on a more open scale, it might be possible to replace many of the laborious methods of measurement hitherto conducted by direct visual observations on the sky itself by somewhat similar methods applied to the photographs.

There existed at the time no comprehensive survey of the Southern skies. A complete catalogue of the stars in the Northern heavens known as the Bonn "Durchmusterung," giving the positions and magnitudes of all stars down to the 9th visual magnitude with a precision at least accurate enough to ensure their identification in the sky, had been formed by Argelander and extended to a portion of the Southern Hemisphere by his successor Schönfeld, but the remainder of the heavens from 23° S. Declination to the South Pole was still comparatively unknown. The photographs I have above referred to suggested a means by which this lacuna might be filled, and no sooner was this idea conceived by Sir David Gill than steps were taken to put it into active execution. Partly at his own personal expense and partly by means of assistance from the Government Grant Fund administered by the Royal Society of London, the necessary equipment and the services of a photographer were secured, and between the years 1885–89 a complete series of photographs of the region extending from 18° S. Declination to the South Pole was obtained.

In order, however, that these photographs might be of value to science, it was necessary that the facts duly recorded on them should be minutely examined and rendered accessible to astronomers generally in the form of a catalogue. As more than 400,000 stars were involved, this in itself was

no light task, and might well give rise to the question as to whether the necessary measurements could not be more advantageously made on the sky rather than on the photographic plates by which it was represented.

The method which was subsequently adopted for the formation of this catalogue forms sufficient answer to this question. The resources of the Observatory were unequal to so large an undertaking, at least without the cessation of a large proportion of its more normal work, and it appeared probable that the photographs would have to remain in the record room of the Observatory, valuable for consultation regarding specific points which might arise, but that their complete discussion would have to be relegated to a perhaps remote future. The difficulty was at this juncture met by a generous offer received from Professor Kapteyn, of Groningen. Professor Kapteyn was himself an enthusiastic astronomer, eagerly desirous of devoting himself to work of this character, with full appreciation of its value, but unfortunately unprovided with an Observatory equipment. He foresaw that, with the aid of a comparatively small laboratory equipment, much of the work of a character which had hitherto been performed by reference to the sky could be effectively and rapidly carried out through the medium of photographic representations thereof. The series of photographs secured at the Cape formed a promising field for research, and he voluntarily undertook the laborious task of the measurement of these plates and the preparation of a catalogue, which has since been issued among the publications of the Cape Observatory and which to-day is in constant use by astronomers concerned with the Southern Hemisphere. Besides many incidental results of high interest, the catalogue forms the basis for statistical investigations of stellar distribution, &c.

The success of the project even in the early stages of its execution pointed to the possibilities of a still more extended use of the photographic methods, and gave a direct stimulus to the study of the details by which its efficiency could be increased. The surveys of Argelander and Schönfeld completed by the "Cape Photographic Durchmusterung" (as the above catalogue is entitled), and independently by a visual "Durchmusterung" emanating from the Observatory at Cordoba under the direction of Dr. Thome could but be regarded as preliminary pioneer surveys; but stupendous as the task seemed the possibility was recognised by Sir David Gill of utilising the photographic method for the production of a complete map of the heavens which should be on a sufficiently large scale and sufficiently precise in its detail to meet all the requirements of modern astronomy of precision.

He succeeded in securing the interest of astronomers generally and in particular of Admiral Mouchez, the then director of the Paris Observatory, at whose instance, with the support of the Paris Academy of Sciences, an international conference of astronomers was invited to meet

in Paris in 1887 to discuss the possibility and desirability of carrying out this extended project.

While the plan in outline met with universal acceptance, much useful discussion took place at this and at subsequent conferences as to the details of its execution, such as the type of instrument to be employed, the scale of the photographs, the duration of exposure which would serve to bring out what should be considered essential detail, &c.

The outcome was that an agreement was arrived at by which the execution of the work was partitioned among eighteen co-operating Observatories, who between them undertook to secure photographs of the whole sky with instruments of similar dimensions and design, and as far as possible similar conditions of exposure. Two series of photographs were to be taken, one of long exposure designed for direct photographic reproduction to form an atlas which should show all stars down to the 14th visual magnitude, and a second series, of shorter length of exposure designed for exact measurement, which would form the basis of a catalogue of precision of all stars to the 11th magnitude. Minor details were largely left to the discretion of the directors of the co-operating Observatories.

It would take too long to describe in detail the progress of this work from its initiation, and I propose, therefore, to confine my attention to the share in it which has been taken by the Observatory over which I have the honour to preside—a share which, partly from the origin of the project and partly from the scarcity of suitably situated observatories of a sufficiently permanent character in the Southern Hemisphere who were able to offer co-operation, has exceeded that assigned to any other single establishment.

The type of instrument agreed upon was the photographic refractor similar in dimensions to that which had been used by the Brothers Henry in Paris, giving pictures on such a scale that one millimetre on the plate corresponds with a minute of arc on the sky. The plates were to be 160 mm. square, so as, apart from the marginal edges, to yield an effective field of view of two degrees square. The area covered by each plate will perhaps be better presented to you by the statement that the length of the edge of the plate corresponds roughly with four times the apparent diameter of the sun or moon, *i.e.*, four suns or four moons photographed side by side on the same plate would just reach from one edge of the plate to the other. On this scale it would require rather over 10,000 plates to cover the whole sky. The programme, however, provided not merely for the photographing of each region once and once only, but that the various regions covered by the separate photographs should overlap in such a way that every star would be contained in two of the regions at least. Thus any doubtful features shown on one plate could be verified by reference to the second plate which includes the same area.

This requirement raised the total number of separate regions to be photographed to 22,054, of which 1,512 were assigned to the Cape Observatory.

The construction of the telescope and the provision of suitable housing accommodation were sanctioned in 1888, and the telescope arrived at the Cape in 1890. About two years was spent in its erection, adjustment, and testing, the delay being largely due to the necessity for returning the object-glass for necessary alterations and the remodelling of the breech-piece which could not be effected locally. From July, 1892, onwards, the work of taking the photographs was steadily proceeded with until its completion in 1910.

At the present time we have stored at the Cape three almost complete series of photographs of the 1,512 regions besides many duplicates and triplicates, which, though not attaining the desired standard of perfection, are still available for reference with regard to many issues that arise.

Of these plates one series of long exposure is destined for direct photographic reproduction; the other two series of shorter duration of exposure or measurement for the purposes of the catalogue. On account of the comparatively insignificant amount of work involved in taking these catalogue plates as compared with the more laborious work of measurement, after its original completion in 1896, it was decided to repeat the whole series of catalogue plates so as to bring the dates of the photographs nearer to the epoch 1900 and thereby more fully attain the ideal before the International Conference of. leaving for future generations as exact a record as possible of the appearance of the heavens at the beginning of the twentieth century.

After some early experiments with a view to ascertaining the most economical means by which these plates might be measured with the desired accuracy, the definitive programme of measurement was commenced in 1897 and completed last year. The number of stars measured on a single plate varies between 45 and 3,431, the total number of star images which have been measured exceeding a million. To illustrate the precision attained, the discordances in the position of a star, relatively to the stars immediately surrounding it, as derived independently from the measures made on two overlapping plates, but rarely amount to as much as a second of arc, *i.e.*, apparent angular distance between the two edges of a half-penny at a distance of about three miles from the observer.

Now, however exactly the measurable features of each plate may be determined, it will be clear that the information thus derived can be of little value without some external data to enable the identification of the region on the photograph with the corresponding region of the sky from which it is derived. A plan of this room might have been useful to enable you to find your seats to-night in positions corresponding with numbers

on your tickets, but I venture to think a stranger visiting Cape Town for the first time would prefer to have been provided with a map of the town which would indicate the position of this hall rather than to have to search the town for a room arranged according to such a plan. So with our photographs—the detailed study of each photograph can be of minor value without some indications enabling us to identify the field shown on the photograph not only in relation to the surrounding fields but in relation to the sky as a whole. It is certainly a desideratum that these indications should be not less precise than those involved in the measures themselves.

Of course if each photograph contained some familiar grouping of stars, such for instance as the constellation Orion, the identity of the region could not be easily mistaken, but the scale on which the plates are taken is such that two such familiar stars are rarely to be found within the limits of a single plate, while many plates are devoid of stars to which accurate positions could have been previously assigned.

The necessity has thus arisen of determining with high accuracy the absolute positions as opposed to the relative positions indicated by the plate itself, of at least two stars contained on each plate. The distance between the images of these stars as compared with the corresponding apparent distance on the sky serves to furnish a determination of the scale of the plate, while the direction of the line joining them serves to fix the orientation of the plate, *i.e.*, enables us to turn the plate round in its own plane so that the true N. and S. line may be placed exactly in a truly horizontal, truly vertical, or, in fact, any other desired direction. With these quantities correctly assigned, either star will be sufficient to correlate the plate exactly with the sky.

In practice, it is customary to refer to a larger number of stars than two on each plate. Not only are the determinations of these necessary "plate constants" strengthened thereby, but in the consistency with which the photographic pictures reproduce the actual distribution of the stars, we have a valuable check on our methods and a test of the faithfulness with which also other features on the sky are represented on the photographs.

For the Cape plates, the determination of the "plate constants," *i.e.*, of those elements which serve as it were for the co-ordination of the isolated maps contained on each plate with a general map of the whole has been made to depend on a number of stars on each plate varying as a rule between 8 and 12. In all, 8,560 stars, as far as possible evenly distributed over the whole of the zone, were selected as comparison stars. These stars constitute a framework to which the detailed results derived from the photographs may be attached, but the structure of which requires to be independently built up.

For such a purpose photographic methods have not as yet proved available, and recourse was necessary to the older method of visual observing with the meridian circle. From observations made in the years 1897–1900 with the transit circle, an accurate catalogue of these 8,560 stars has now been formed, and has been utilised for the purpose of standardising each of our plates. The heavy arithmetical work involved in applying to each of our original measures, over two millions in number, the derived correction to refer the whole to a common standard is now rapidly proceeding and at the present time is about half completed.

I have above referred to the catalogue of 8,560 comparison stars as a framework for the support of the more extensive photographic catalogue. Such a framework, at least on the basis on which this one was constructed, is not entirely self-supporting, and it thus behoves us to carefully consider its foundations and to ensure that they possess the necessary solidarity.

Not the least of the important questions brought up for discussion at the last meeting of the International Committee charged with the conduct of the photographic work, was that of the steps to be taken for this purpose.

It was recognised on all sides that even the best existing meridian catalogues were inadequate, and that they would have to be supplemented by extensive additional observations. The main object of the discussion was to secure the most extensive co-operation from observatories provided with suitable meridian equipment, and to classify the work in various grades of accuracy, so that each establishment might devote itself primarily to that branch for which its equipment was best adapted, at the same time keeping in view the co-ordination of its work with the larger scheme. The resolutions adopted have since been favourably received by meridian observers, and we may look in the future to a systematic organisation of meridian astronomy throughout the world, the results of which, apart from the mere economic aspect, cannot fail to be of the highest importance to science.

It may well be asked, What is the use of such a chart as you have been describing? or, Will it repay the enormous cost involved in compiling it?

As regards its use, I endeavoured to indicate in my address last year some of the problems which awaited solution and which serve to inspire the astronomer in the conduct of the lengthy routine operations involved. These motives are perhaps for the most part intellectual rather than utilitarian, and it is possible, even probable, that to many of the questions arising answers which will afford complete satisfaction will not be forthcoming at least for a generation or two to come.

I think I am sufficiently voicing the view of those who took part in the original discussions at Paris when I state that they, as a body, attached greater importance to the complete and thorough systematic record of the phenomena prevailing during their own generation than to the immediate interpretation of these phenomena. It was felt to be a scientific duty, incumbent on them, to provide so far as lay within their means and capacity data which should be beyond reproach. By this means they were preparing the ground and planting the seed which they hoped would yield a rich crop of scientific results, even though it should remain for their children's children to reap the harvest.

Much has already been attained. The ghosts which beset the use of photography in relation to the science of exact measurement have in a large measure been laid, and photographic methods have now been successfully used for some of the most delicate measurements ever attempted even by direct visual operation.

I have in mind such questions as the determination of the distances or annual parallaxes of the fixed stars and of the parallax of the sun, in connection with which, under the auspices of the Paris Conference, an extensive photographic campaign combined with visual methods was undertaken on the occasion of the near approach of the planet Eros in the years 1900–01.

The discovery of the latter planet was itself a product of photography, while by similar means the number of known minor planets has within the last few years increased by leaps and bounds, until at the present day they are nearly seven hundred in number.

Photography has also been prolific in the discovery of variable stars and new stars, and the tracing of their light changes. All these purposes will be greatly facilitated by the existence of a reliable chart or catalogue containing more especially the fainter stars about which our exact knowledge hitherto has been almost non-existent.

Time must elapse before we can expect to be able to evaluate with certainty the slow changes of position due to proper motion at least in relation to the previously uncatalogued faint stars, but this is to-day one of the greatest desiderata for the advancement of our knowledge of the universe, and is one of the purposes for which the photographic catalogue was primarily intended.

By photographic methods and by co-operative effort throughout the world alone has it been possible to collect evidence on a sufficiently wholesale scale, so that already we are beginning to feel the solution of some of the most profound problems relating to the universe almost within our grasp.

SOME NEW SOUTH AFRICAN SUCCULENTS AND OTHER PLANTS. Part IV.

By R. Marloth, Ph.D., M.A., F.R.S.S.Af.

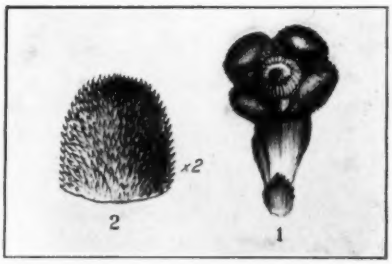
(Read May 17, 1911.)

Among the plants described in this paper are three species of special interest, viz., one of *Cytinus*, one of *Borbonia*, and one of *Anacampseros*. The *Cytinus* is noteworthy as it constitutes a second species of Rafflesiaceæ for South Africa, the *Borbonia* is of economic importance, being the source of a colonial tea, viz., rooibosh tea, and the *Anacampseros* is another example of a mimicry-plant, of which eight species were described in the previous papers.

RAFFLESIACEÆ.

Cytinus capensis, spec. nov.

Planta 10–12 cm. alta, dioica; caulis squamis ovatis, brunneis obtectus; inflorescentia mascula terminalis, racemoso-corymbosa, pauciflora. Flores



Cytinus capensis, Marl.
1. Flower of Male Plant. Nat. size.
2. Segment of Perianth. × 2.

saturate-sanguinei, 4-partiti, segmentis concavis, rotundatis, fimbriatis, tomentosis. Planta feminea ignota.

This plant was found growing on the roots of a shrub (*Metalasia muricata*) in the Cape Flats. The stems are only 4–5 in. high, just reaching to the surface of the sandy soil and showing the flowers almost flush with the ground. The colour of the flowers is a dark claret, the pollen is nearly white. In our other species, *C. dioicus*, the flowers are bright orange, about twice the size, 6-parted, and more tubular.

It appears to be very rare, for only two groups of it were found by Mr. E. Dyke, although, having learnt from me what an interesting find he had made, he searched the locality repeatedly. Flowering in August in the Cape Flats near Zeekoe Vley. Marloth, No. 4978.

Up to the present three species only of this interesting genus were known, viz., one in the Mediterranean region, one in Madagascar, and one in South Africa.

PORTULACACEÆ.

Anacampseros albissima, spec. nov.

Caudex brevis, depressus; caules plures recurvi, densissime stipulis albissimis obtecti. Stipulæ spiraliter adpressæ, breviter ovatæ, retusæ, non-laciniatæ, basi angustatæ et barbatæ. Folia succulenta, brevissime-renata. Flores ignotæ. Capsula globosa.

Stems pure white, 1–4 cm. long and 4 mm. thick, more or less recurved. Stipules broadly ovate, entire, very concave, each stipule holding the leaf next above it in its hollow. Leaves 2 mm. broad and 1 mm. long.

This plant has the habit of *Anacampseros papyracea*, but differs from it (1) by its smaller size (about one-half) and thinner stems, (2) the shape of the stipules, which are shorter in proportion, (3) the shape of its leaves, which are broader than long.

The flowers remain enclosed within the apical stipules as in *A. papyracea*, but produce fruits. The stalks of the capsules lengthen on ripening sufficiently to free them from the surrounding stipules.

This species is like *A. papyracea*, a mimicry-plant, for both occur only, as far as known, on fields of white quartz. The latter species is found in several districts of the karroo, but neither myself nor any of the other collectors who have sent it to me did meet with it in other surroundings. The same is the case with this species, which I found in several localities of German South-West Africa, but only on reefs or outcrops of pure white quartz, where the plant could be detected only with great difficulty.

LEGUMINOSÆ.

Borbonia pinifolia, spec. nov.

Frutex bipedalis, foliis simplicibus, teretibus, filiformibus. Flores racemosi, parvi; calyx subregularis, 5-dentatus, *Rafniæ* similis; corolla

lutea sed carina et vexilli apex sericeæ. Ovarium bi-ovulatum. Legumen lineare, acuminatum, seminibus duobus.

This plant has the appearance of a *Rafnia*, but on account of the structure of the ovary and the silky corolla it must be placed into the genus *Borbonia*. Here it does not fit into either of the two groups formed by Harvey in the Flora Capensis, for only the alæ are glabrous.

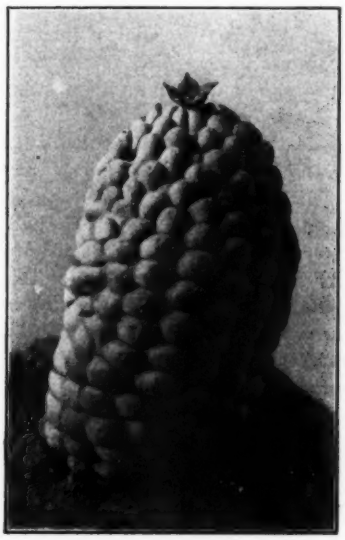
The plant is of special interest, as it supplies the "rooibosh-tea,' which is now so largely used in South Africa either under this name or as "naald-thee" or "koopmans-thee." The shrublet occurs apparently only on the Cedar Mountains near Clanwilliam and Wupperthal.

Flowering December–January. Marloth, No. 4728.

ASCLEPIADACEÆ.

Trichocaulon meloforme, spec. nov.

Caulis simplex subglobosus vel e basi paullo-ramosus, ramis globoso-



Trichocaulon meloforme, Marl.
⅔ Nat. size.

ovatis. Caulis ramique mammillis obtusis obtecti. Flores ex areolis superioribus, 1–3, breviter pedicellati. Corolla rotato-campanulata, tubo

2–3 mm. longo, lobis abrupte-angustatis, apice recurvis, superne maculis fusco-purpureis tectis. Coronæ exterioris segmenta profunde bipartita, lobis acutis, valde arcuato-divergentibus. Coronæ interioris segmenta linearia antheris incumbentibus, arcuato-elongatis, apice haud divergentibus, basi longe-cornutis.

The plant is 2–3 in. high, nearly globose, the stems solitary or 2–3 from the same root; the slightly raised tubercles of the surface are without bristles, greyish green; the flowers appear at the apex, 1–3 from the same point, opening in succession. The tube of the corolla is shallow, cup-shaped, the segments are broadly ovate, abruptly and shortly acuminate, the points when the flower has just opened recurved, but later on suberect. The points are dark-maroon, while the base of the corolla-lobes and the visible portion of the tube are yellow, speckled with dark-maroon markings. The outer side is a dark claret. The outer corona is quite similar to that of *T. cactiforme*, the lobes of two neighbouring segments arching towards each other and forming a pair of mandibles. The inner corona, however, differs from that species by its elongated lobes, which reach to the level of the outward corona segments and also bear an anterior curved process, which stands between the two "mandibles," almost touching their tips. The size of the flowers varies according to the state of the plants, for in robust specimens they may be 10 mm. in diam., while in others they are only 6 mm.

Found between weathering granite-boulders near Aus in German South-West Africa (alt. 1,400 m.) and flowering in my garden at Capetown in March, 1911. Marloth, No. 4874.

A few years ago only one species of *Trichocaulon* without bristles was known, viz., *T. cactiforme*, but the Flora Capensis (vol. iv., Part 1, page 889, published in 1909) brought two others of this group, and shortly afterwards a third one, also sent to Kew by the writer, was named *T. pictum;* hence within a few years the number of species of this section has risen from one to five.

They are all very similar in habit, hence in order to facilitate their recognition I attach the following brief synopsis.

A. Segments of outer corona bipartite, each segment being formed of 2 almost independent lobes.
  a. Inner corona-lobes not produced beyond the anthers .. .. 1. *T. cactiforme* (Hook), N.E.Br.
  b. Inner corona-lobes produced beyond the anthers.
    1. Inner corona-lobes with a conspicuous anterior horn, standing between the segments of the outer corona .. .. 2. *T. meloformе*, Marl.
    2. Inner corona lobes without a dorsal appendage .. .. 3. *T. Marlothii*, N.E.Br.

B. Segments of outer corona deeply 3-lobed.

a. The middle lobe shorter than the lateral lobes, entire .. .. 4. *T. simile*, N.E.Br.

b. The middle lobe broader than and nearly as long as the lateral lobes, bifid .. .. 5. *T. pictum*, N.E.Br.

* This species appears to be very similar to, or identical with, one from Great Namaqualand, described by Berger as *T. Dinteri* (Stapelien und Kleinien, p. 30, 1910).

There is another species of this group mentioned in the same book, viz., *T. pedicellatum* Schinz, but without a description of the corona.

IRIDACEÆ.

Gladiolus Florentiæ, spec. nov.

Planta acaulis. Cormus globosus, fibris mollis obtectus. Folia 2–3, subsecunda, breviter-lanceolata, striata, glabra. Racemus pauciflorus, subsessilis. Flores 2–5, lutei, spathis viridibus, segmentis subæqualibus.

This pretty little plant resembles in its foliage almost a Babiana, but the leaves are neither plicate nor hairy. The flowers are nearly 2 in. long and 1 in. wide at the mouth, of a deep golden yellow, otherwise of the typical structure of Eu-Gladiolus.

Frequent in stony ground of the Karroo near the Great Tygerberg in the district of Prince Albert. Flowering in May, 1907. Marloth, No. 4452.

ON THE EARLY BABYLONIAN ECLIPSE OF THE SUN.

By E. Nevill, F.R.S., F.R.S.S.Af.

(Read May 17, 1911.)

On the fourteenth line of Tablet No. 35968 of the British Museum Collection Mr. King has deciphered the record :—

"On the twenty-sixth day of the month Sivan in the seventh year the day was turned into night and fire in the midst of heaven [. . .]."

Mr. King regards this as the record of an eclipse of the sun seen at Babylon, and Mr. Cowell has identified it with the eclipse of −1062 July 31st (MN., Roy. Ast. Soc., 1905, pp. 861–869).

The Tablet bearing the cuneiform record when complete must have been about 5 inches broad, and probably not less than 6 inches in length ; but in its present damaged state it has a breadth of only 4 inches and a length of only $3\frac{1}{4}$ inches, the bottom half of the Tablet having been destroyed, and a portion of the lower part of that remaining has been rendered illegible. Each face is divided into two columns, so that altogether there are four columns of inscription, but almost the whole of the inscription on the first and fourth columns has been so damaged as to be unreadable. Apparently the complete Tablet must have contained from sixty to seventy lines of inscription in a complete column.

On the obverse of the Tablet, of column I there remain readable only portions of the upper twenty-two lines, in too fragmentary a condition to have their real meaning understood. Of column II, the upper twenty-two lines can be deciphered sufficiently well to enable their meaning to be understood, whilst there are six additional lines which can be partially read. The record is on the fourteenth line of this column, and can be read with certainty except the last word. On the reverse of the Tablet, of the IIIrd column, the second to the nineteenth lines from the bottom can be read fairly well, but the rest is illegible, whilst of the IVth column there only remain fragments of some eight lines, apparently the tenth to the eighteenth lines from the bottom. These details are of importance, and though some small uncertainty may attach to my numbering of the lines on the IVth column, this is of little importance, as it

is only the IInd and IIIrd columns that have to be dealt with in what follows.

If my reading be correct, and the Tablet when complete had sixty-five lines to a column, there must be thirty-three lines missing or only partially legible on the bottom of the IInd column, and forty-six lines missing from the top of the IIIrd column; or in all a gap of seventy-nine lines missing between the last legible line of column II to the first legible line of column III. But if, as is probable, the Tablet when complete was longer than 6 inches, then the number of missing lines may be considerably over a hundred.

The first point to be considered is, Is this record to be read as indicating the occurrence of an eclipse of the sun?

There is some uncertainty on this point, for the event is not recorded in the words usually employed to denote an eclipse of the sun. Mr. King thus deals with this question:—

"It will be noted that the word for an eclipse, *atalû*, usually expressed by the composite ideogram AN-MI, 'heaven-darkness,' is not employed in the passage in question, and only the effect of an eclipse of the sun is recorded in the words, 'the day was turned to night.' It might, therefore, be urged that the cause of the portent should be traced to atmospheric rather than to astronomical conditions. It is true that an exceptionally severe thunderstorm might have darkened the heavens sufficiently to justify a poet using the language employed in the Chronicle; but the document is not a poetical composition, and in another of the portents which was undoubtedly caused by a thunderstorm, the Chronicle ascribed the phenomenon to the agency of Adad, the storm-god.* The only other possibility would be to trace the cause of the portent to a dust-storm. But any one acquainted with Mesopotamia will have vivid recollections of the frequent occasions on which he has experienced the discomfort arising from storms of this nature, and to an inhabitant of the country even a severe dust-storm would have little of novelty about it. In fact, there is small probability that so common an occurrence would have been regarded as a special sign from heaven, and incorporated in a register of portents alongside of such wonderful happenings as the visible appearance of divine beings and the slaughter of wild beasts in the streets of Babylon.

"We are thus forced to accept the occurrence of a solar eclipse as the most probable explanation of the phrase that the day was turned to night.†

* Column III, line 19.

† Of course the absence of the actual word for an eclipse from the passage in the Chronicle renders the objection, that the turning of day into night must have been due to other than astronomical conditions, incapable of disproof. The question is one of greater or less probability. . . .

We can well imagine the terror with which a total eclipse of the sun would have been regarded by the ancient Babylonians, and there would be nothing more likely than to find a record of such an event in a Chronicle devoted entirely to religious matters and portents of an unusual nature. If, therefore, it could be shown that an eclipse did actually take place, which with regard to date and line of totality satisfies the conditions attaching to the record, there would be little risk in accepting the astronomical interpretation of the phrase " ("Chronicles Concerning Early Babylonian Kings," vol. i., pp. 233–235).

Mr. King's words seem a fair and impartial summing up of the question, though it is true that Mr. King seems to have overlooked the fact that three thousand years ago, when the region around Babylon was in much closer proximity to the sea than at present, and was highly cultured and well irrigated, these dust-storms would have been far less common than at present, as well as the fact that severe thunderstorms *are* included in the list of portents; yet few will be found to dispute his conclusion that the portent recorded is not likely to have been either a dust-storm or an ordinary severe thunderstorm. Still there is another description of storm to which Mr. King does not refer, the dangerous " dry storm " that at rare intervals sweep up the border of the Persian Gulf and over Babylonia; a storm unaccompanied by either wind or rain, coming up in the form of a dense high cloud, bordered by vivid lightning, but with only occasional distant deep peals of thunder. These are so exceptional that possibly Mr. King has not experienced one, and they might well be regarded as portents worth recording as so many years elapse between their occurrence, though they are more frequent on the coasts of South-East Arabia and Africa.

Yet, as Mr. King justly remarks, it is a question of greater or lesser probability, and the greater probability is certainly in favour of the inscription recording the occurrence of a solar eclipse, if such an eclipse can be found which might have been visible from Babylon.

If the inscription may be taken as recording the occurrence of an eclipse of the sun, it remains to determine its probable date. The following note by Mr. King deals clearly with this matter :—

" In column II of the Chronicle the eclipse is recorded to have taken place 'in the seventh year,' that is to say, 'in the seventh year of a Babylonian king whose name occurred in the lower part of column I of the Chronicle, which is now missing.' But the date may be fixed within certain limits from other indications in the text. Columns III and IV of the Chronicle are concerned with the reign of the Babylonian king 'Nabû-mukîn-apli,' one of the earlier kings of the Eighth Dynasty, and probably its founder. It is therefore certain that the king whose reign is dealt with in column II reigned before and not after 'Nabû-mukîn-apli,'

and from the amount of text missing it is probable that the king was amongst 'Nabû-mukîn-apli's' more immediate predecessors.

"We also know from the Chronicle that this unknown king reigned for at least seventeen years, since his seventeenth year is mentioned. But only two of Nabû-mukîn-apli's immediate predecessors reigned as long as this—Simmash-shîkhu, who reigned seventeen or eighteen years, and Eulbar-shakin-shum, who reigned seventeen or (according to the Dynastic Chronicle) fifteen years. From the Babylonian 'List of Kings' we know that only three years and five months separated the end of Simmash-shîkhu's reign from the beginning of that of Eulbar-shakin-shum's. Therefore the seventh year of Simmash-shîkhu was separated from the seventh year of Eulbar-shakin-shum by twenty years and five months or twenty-one years and five months. This gives us the difference in date involved by the identification of our unknown king with Simmash-shîkhu and Eulbar-shakin-shum respectively. Of these two kings there is slightly more to be said in favour of Simmash-shîkhu, the earlier of the two, since the Dynastic Chronicle assigns only fifteen years to Eulbar-shakin-shum.

"To accurately fix the date of either Simmash-shîkhu or Eulbar-shakin-shum is unfortunately impossible at present, as may be seen from the following table, which gives the seventh year of each of these kings according to the principal schemes of Babylonian chronology published during the last few years:—

		Seventh Year of Simmash-shîkhu.	Seventh Year of Eulbar-shâkin-shum.
Rost	1897	B.C. 1106	B.C. 1084
Sayce	1899	1090	1069
Hommel	1886	1075	1054
Hommel	1898	1037	1015
Winckler.....	1892	1074	1054
Winckler.....	1894	1031	1011
Rogers.....	1900	1068	1047
Delitzsch	1891	1044	1022
Peiser	1891	1042	1021
Neibuhr	1896	1031	1008
Lehmann	1898	974	953

"But the table will suffice to show that, if the unknown king be identified with either Simmash-shîkhu or Eulbar-shakin-shum, the eclipse of B.C. 1070 or B.C. 1063 are more probable than those of B.C. 1124 or B.C. 1117.

"It should be stated, however, that the end of column II and beginning of column III which are missing from the Chronicle, may possibly have covered a longer period than that between the reigns of Simmash-shîkhu and Nahû-mûkin-apli. In that case there are two kings in the

preceding dynasty, one of whom reigned seventeen years and the other twenty-two years, with whom the unknown king of the Chronicle might be identified. But, as already stated, the probabilities are in favour of his identification with Simmash-shîkhu."

This last paragraph of Mr. King's comments may be considered in more detail.

Adopting Mr. King's identification of Nahû-mûkin-apli as the founder of the Eighth Dynasty, in which he is in accord with Sayce and Winckler, the seventh year of Eulbar-shakin-shum, the founder of the Sixth Dynasty, would be nineteen years earlier than the first year of Nabû-mûkin-apli, and the seventh year of Simmash-shîkhu would have been forty-one years before this epoch. If the unknown king was neither of these, he must have been one of the kings of the Fourth Dynasty, probably either Merodach-nadin-akhi, whose seventh year would have been about eighty years preceding the first year of Nabû-mûkin-apli, or Merodach . . . whose seventh year would have preceded this epoch by from one hundred and fifty to some one hundred and eighty years.

Now the missing portion of the Chronicle between the bottom of column II and the top of column III it has been seen is from eighty to over one hundred lines.

What interval of time does this represent?

In column II of the Chronicle the eleven lines, 12–22, cover a period of ten years, from the seventh to the seventeenth year, of the unknown king's reign. Then on the twenty-sixth line is a reference to the fourteenth year of some king. Query the same one or that of a successor? On this point Mr. King remarks :—

"If the fourteenth year mentioned in column II line 26 of the Chronicle does not belong to the same reign as the seventeenth year in lines 19 and 20, we may refer the date in the upper part of the column to Simmash-shîkhu, and the fourteenth year in line 26 to Eulhar-shakin-shum; but if the fourteenth year, as is more probable, is merely mentioned out of order, and belongs to the same reign as the seventeenth year, we may refer all the dates preserved in the IInd column to the same king" ("Chronicles Concerning Early Babylonian Kings," vol. i., p. 224).

Yet this misplacing in order would be exceptional. It is true it does occur in column III, where lines 6–13 state that "(6) In the month Nisan in the eighth year of Nabû-mukîn-apli the king (7) the Aramaeans made war and the Ferry Gate of the City of Har-bel-mâtâti (8) they captured: and the king crossed not over and Nabu went not (to Babylon) (9) and Bel went not forth; on the eve of the New Year's festival in E-sagila according to the word of [. . .] made the offering. (10) In the month Nisan in the nineteenth year of Nabû-mukîn-apli, the king, the same

thing occurred, (11) and the appointed offering was made. In the month Tammuz in the sixteenth year a lion whose entrance into the city none (12) had beheld, on the western bank (of the Euphrates) in the eighth plantation (13) they beheld and they slew him." But here it is simply as an addition to the event of the eighth year, that it mentions that the same religious irregularity occurred also in the nineteenth year, and then the record goes on to take the subsequent events in their due sequence. But there is no such connection between the events mentioned on lines 19–23 of column II as occurring in the seventeenth, and that mentioned on line 26 as happening in the fourteenth year. Hence it would appear the more probable that there has occurred a change from one reign to another between lines 23 and 26, such as Mr. King regards as possible.

In the portion of column III which has been preserved, the whole of the events appear to have happened during the thirty-six years of the reign of Nabû-mukîn-apli. The fourth line of those decipherable refers to his seventh year, and the nineteenth line to an event of his twenty-sixth year, or fifteen lines cover the events of nineteen years. On column II, we have seen that eleven lines cover the events of ten years. Judging from this, the average would seem to be about a line to a year: hence the missing eighty to over a hundred lines between the end of the text in column II and the beginning of the text in column III might be expected to cover a period of at least a century rather than the short period of twelve years to the fourteenth year of Eulbar-shakin-shum, or the thirty-one years to the seventeenth year of Simmash-shîkhu. It would rather suggest that the unknown king of column II was more probably Merodach-nadin-akhi, whose seventeenth year was about seventy years earlier than the first year of Nabû-mukîn-apli, or even the king whose name began with Merodach . . ., whose seventeenth year must have preceded this epoch by from one hundred and thirty to one hundred and seventy years.

The only drawback to this reading is that Mr. King states that on lines 4 and 5 of the short portion legible of the text near the bottom of the IVth column there occurs the *end* of the name of the king Nabû-mukîn-apli.* ("Chronicles," &c., vol. i., p. 222.) From this Mr. King concludes that the whole of column IV, like the preserved portion at the end of column III, refers to the events of the reign of this king. As the missing upper portion of column IV contained forty to fifty lines of text, this would cause it to appear as if though fifteen lines sufficed to deal with the events between the seventh and twenty-sixth years of his reign, yet forty

* From the reproduction of the inscription ("Chronicles," &c., vol. ii., p. 177) it would appear that though only the end of the name appeared on line 4, yet that the whole of the name could be deciphered on the fifth line. If so there could be no doubt about the name of the king being the same as that occurring so often in column III.

to fifty lines were required to chronicle the events of the last ten years of his reign. This is not what would have been expected, for it can scarcely be supposed that the strictly chronological arrangement preserved on the other three columns should be departed from only on the fourth. From analogy these forty to fifty lines from the end of column III to the first legible lines of column IV would have been expected to cover a period of at least forty to fifty years. There is a gap of some fifty to eighty years between the end of Nabû-mukîn-apli's reign and that of the next king whose name is known, Shamash-mudammiq, corresponding to some four or five kings whose names are unknown. Is it improbable that one of these kings may have also borne the name Nabû-mukîn-apli, in the same way as found in repeated other instances, and that it is to events of the reign of a second king of this name that the end of the column IV is devoted? If this supposition be permissible, then the events related in column II would be more likely to appertain to a king reigning about a hundred to a hundred and fifty years before Nabû-mukîn-apli, rather than to one reigning only twenty to forty years before.

From Mr. King's notes it has been seen that even if we adopted his identification of the unknown king as probably either Simmash-shîkhu or Eulbar-shakin-shum, the eclipse may have been one occurring in any year between B.C. 954 and B.C. 1105—a pretty wide limit. If, however, the unknown king is looked for in the Fourth Dynasty, rather than in the Fifth or Sixth Dynasty, a possibility which Mr. King admits ("Chronicles," vol. i., p. 235, note 2), then the limit must be extended from B.C. 954 to B.C. 1240. Mr. King considers the probable date to be within the eleventh century; from the data given, I should have supposed it as not unlikely to have been the twelfth, or even earlier.

The last point to be considered is the date. The record is clear that it was "on the 26th day of the month Sivan in the seventh year." What are the limiting days between which the 26th Sivan could occur from what is known of the Babylonian Calendar. Under ordinary conditions the 26th Sivan must have been some day between June 3rd and July 10th, and except through some altogether irregular interference with the Calendar, could not have occurred outside the limits May 23rd and July 16th. There seems no evidence whatever that the Calendar was ever so manipulated that the 26th Sivan could have been delayed so excessively late that it could have fallen on July 31st. On this point Mr. King remarks :—

"The obvious objection to the acceptance of this identification is the equation Sivan 26th = July 31st. For it would follow from this equation that, although the equinox occurred about April 1st, yet the Babylonians did not begin that year till about May 4th. The only conceivable explanation of this would be that the month beginning about April 4th was an inter-

calary month. But intercalary months were only inserted to bring the calendar into harmony with the season, and the insertion of one in the above circumstances would imply a very inaccurate system of observation in the eleventh century B.C., or the existence of some custom with regard to the insertion of intercalary months at this period of which we have no other evidence or indication " (" Chronicles," vol. i., p. 208).

Intercalary months were inserted when it was known that the equinox would otherwise fall later than the middle of the month Nisan. For the first Nisan to fall so late as May 4th would mean that though an intercalary month should have been inserted *two* years before, this was not done either on that year or on the year following, but was *two* years late : a thing inexplicable, because the necessity of so inserting an intercalary month must have been manifest at *four* equinoxes, two spring and two autumn. There is evidence that on rare occasions, when by some oversight, perhaps the result of persistent cloudy weather, an intercalary month was not inserted when this should have been done, that when the omission was revealed on the occurrence of the autumn equinox it was rectified by the insertion of an intercalary month after the month Elul as a second Elul.*

Assuming that the record establishes the occurrence of a total eclipse of the sun, visible from some place in Babylonia during the period −1250 to −950, and in the months of May, June, or July, it remains to be seen if it can be identified with any particular eclipse.

I have examined every eclipse occurring between −1250 and −920 which could have been total within ten degrees of latitude during the months of May, June, or July. They are some seventy in number, and

* Mr. Fotheringham draws attention to an account of the early Babylonian Calendar given by Signor Schiaparelli in " Scientia," vol. iii., pp. 17–21, from which he draws the conclusion that there was no fixed or uniform method of intercalation, and that it is impossible to assert with confidence that a particular Julian date fell within a particular Babylonian month (*Observatory*, March, 1909, p. 141). I have not seen this paper, and so cannot judge the evidence that has led to this remarkable conclusion; but it would require the most explicit and definite evidence from contemporaneous records to establish a conclusion so exceptional in character and so irreconcilable with what is known concerning systems of Oriental chronology. No evidence drawn from incidental coincidences or adopted identifications of epochs would suffice for this purpose. If data sufficient to establish this remarkable conclusion really does exist, apparently it has escaped hitherto the notice of the best authorities. If it be true that it is impossible to state definitely the particular Babylonian month corresponding to a particular Julian date, as intercalary months were inserted at all periods of the year, then it would go far to destroy the value of their ancient eclipses of the sun for deducing the true value of the secular accelerations of the lunar angular elements, or, indeed, their value for almost any chronological purpose. For as usually the year is uncertain within wide limits, and the particular place of observation uncertain within still wider limits, as a rule unless the month be known there is little to identify the eclipse with any certainty.

an approximate calculation showed that the only eclipses which could possibly correspond to the record are the following:—

−1235	May 26th
−1217	June 5th
−1163	July 8th
−1135	June 28th
−1123	May 18th
−1116	June 28th
−1069	June 20th
−1062	July 30th
−1014	July 11th
− 956	May 31st
− 947	May 22nd

These selected eclipses were then carefully computed according to Hansen's method as employed by Oppolzer, making use of the tabulated data given in the "Syzygien Tafelu," after removing the empirical corrections applied by Oppolzer.

Taken unchanged, this would yield results corresponding to Hansen's final data as given in the "Darlegung," after adding eleven seconds to the secular motion of the node. But as it was deemed best to make the fundamental calculation of the eclipses on the basis of pure theory, there were applied the requisite corrections to the secular acceleration of the mean longitude and to the secular motion and secular accelerations of the longitude of the lunar perigee and node to reduce them from the values derived from observation to the values derived from pure theory. These purely theoretical values, assuming the epoch of T to be 1800, were taken as—

Mean longitude	$=l=$	+17325593·796″T	+ 6·180″T²	+0·0062T³
Longitude of Perigee	$=A=$	+ 146435·473	−38·900	−0·0389
Longitude of Node...	$=B=$	− 69679·281	+ 6·560	+0·0066

Values agreeing fairly well with those derived by theory by Professor Brown, except in the case of the secular motion of the mean longitude, which has to be deduced from observation, and for which Professor Brown's value seems to be too large.

These correspond to—

$l=$ Hansen's Darlegung Values...	−30·00″T	−6·377″T²	−0·006349″T³
$A=$,, ,, ...	+12·88	−0·322	−0·000322
$B=$,, ,, ...	+33·83	−0·064	−0·000064

and form similar corrections to the values adopted as the basis of Oppolzer's "Syzygien Tafeln" before the application of his empirical terms, except that in the case of the coefficient of T in the value of B,

which exceeds Hansen's "Darlegung" value by +11·0″, the correction deduced by Newcomb, so that the correction to be used becomes 22·83″.

Tables were then formed of the necessary corrections to the quantities T, L, Z, P, Q, and the arguments I., II., . . . VIII., at the different epochs in order to reduce these factors to the values corresponding to the adopted theoretical basis. From this amended data there were calculated the complete values of T, L, Z, P, Q, $\log p$, $\log q$, $\log \Delta L$, and μ_a'; and in turn from these were computed the values of μ, $\log \gamma$, G, H, $\sin g$, $\cos g$, $\sin k$, $\cos k$, and n employed in the calculation of the path of the shadow of the moon. Finally the line of central totality was computed according to the formula on p. xxii of the "Canon der Finsternisse."

The results obtained were as follows :—

Latitude of Central Path of Totality on the Meridian of Babylon. East Longitude 44·40°.

−1235	May 26th	ϕ = +32·43°	−25·69Δl	− 8·39ΔB	−2·28ΔA	+36·39$\Delta l'$
−1217	June 5th	= +32·76	+10·89	− 6·67	−0·58	− 4·87
−1210	July 18th	= + 9·46	+20·69	+ 5·25	+0·94	−27·82
−1163	July 8th	= +27·16	+ 1·54	− 5·61	+0·19	+ 4·43
−1135	June 28th	= +41·31	+15·61	+ 8·40	+0·39	−25·76
−1123	May 18th	= +41·09	− 7·36	− 5·34	+0·41	+13·62
−1116	June 28th	= +22·53	− 1·86	+ 5·13	+0·09	− 3·51
−1069	June 30th	= +18·41	−17·29	− 6·06	+0·30	+25·07
−1062	July 31st	= +36·33	− 2·25	+ 3·44	−0·18	− 1·27
−1014	July 11th	= +36·36	+12·38	− 8·32	+0·48	− 7·20
− 956	May 31st	= +43·25	−25·06	−10·69	+1·27	+38·28
− 947	May 22nd	= +43·98	−19·00	+ 8·01	+1·51	+10·78

where Δl, ΔB, ΔA are corrections to the adopted mean longitude, longitude of Node, and longitude of Perigee at epoch of Eclipse expressed in degrees of arc; and where—

ϕ = Latitude of centre of path of totality on crossing the meridian of Babylon.

The latitude of Babylon may be taken as 32·57° North, with an uncertainty of about half a degree, as it is quite uncertain from which of the temples in or near Babylon that the eclipse was observed.

Within what limits of latitude must the central line of totality be brought on crossing the meridian of Babylon before it can be held to satisfy the record of the observation?

The semi-width of the path of totality may be taken as from one-half to three-quarters of a degree of latitude; the uncertainty as to the place of observation amounts to about half a degree more, whilst the doubt as to the true values of the terms of very long period renders the true value of the moon's motion in mean longitude sufficiently doubtful as to make the true path of totality uncertain by fully a degree of latitude. Hence it

may be assumed provisionally that any eclipse whose computed path of central totality passes within some two degrees of the assumed latitude 32·57° of the centre of Babylon will satisfy the observation.

An examination of the results obtained for the computed path of the central line of eclipse on the basis of the adopted theoretical values of the secular motions of the lunar elements show that the paths of the eclipses of −1235 May 26th and −1217 June 5th both passed over Babylon. Both these eclipses were annular eclipses, approaching total eclipses in character, and either would serve to represent the recorded observation that the "day was turned into night and fire [appeared] in the midst of heaven," as the corona and red flames would be conspicuous. This day also corresponds with that of the "twenty-sixth day of the month of Sivan," for though ordinarily this day would lie between June 3rd and July 10th, it is quite possible that it might have fallen as early as May 26th. The years are much earlier than would have been assigned by Mr. King, but it has been shown that the record admits of a much earlier date being possible—a date of from 120 to 180 years prior to that of the accession of the king Nabû-mukîn-apli. The year of the accession of this king is uncertain by thirty to fifty years. Sayce, Rogers, Tofteen, Hommel, and Winckler would place it in about -1040 ± 20 years, though subsequently the last two would bring it down to about -1000 ± 20 years. Taking the earlier date, it is possible that the king of unknown name referred to in the record may have reigned from 120 to 180 years earlier, which would bring the epoch of his reign up to −1160 to −1220, with an uncertainty of about twenty years. The years −1235 to −1217 are very early, therefore, but not impossible.

Adopting the date -1040 ± 20 years for that of the accession of Nabû-mukîn-apli, the king Merodach-Baladin I., of the Kassite Dynasty, must have reigned from the year −1236 to −1223, and the king Marduk-akhi-irbi of the Isin Dynasty from −1219 to −1201, with a probable uncertainty of some twenty years. Hence the seventh year of one of these kings may be regarded as coinciding with either the year −1235 or −1217, and so be brought into accord with the record. If the lower date be adopted for the accession of the king Nabû-mukîn-apli it would throw the eclipse into the reign of the earlier Kassite king Adad-shum-itsur, who reigned for thirty years; on this assumption from −1242 to -1202 ± 20 years.

The paths of the shadow of these eclipses are—

East Longitude.....		38°	40°	42°	44°	46°	48°
North Latitude. Eclipse ...	−1235	26·2	28·2	30·1	31·9	33·6	35·2
North Latitude. „ ...	−1217	35·0	34·3	33·6	32·9	32·2	31·4

The eclipse of −1235 occurs before noon and the eclipse of −1217 shortly before sunset.

The drawback to the purely theoretical data adopted in the previous computations is that it does not adequately represent the more modern observations of the moon during the period 1660 to 1900. In particular the adopted numerical values for the secular motion of both the perigee and node of the lunar orbit are much smaller than indicated by the observations, and to represent these properly the numerical value of the secular motion of the perigee must be increased by fully 10″, and that of the secular motion of the node by some 30″ per century. Hence it is probable that the values for these elements as deduced, hitherto, from theory are not quite complete, owing to some small constituents having been overlooked.

If the corrections indicated by the observations be applied, and the new data regarded as the theoretical data supplemented, it yields for the latitude of the point where the central path of the eclipse crosses the meridian of Babylon the amended values—

Eclipse of −1235	Latitude = +30·56°	Eclipse of −1116	Latitude = +23·76°
−1217	= 31·16	−1069	= 16·97
−1210	= 10·20	−1062	= 37·14
−1163	= 25·72	−1014	= 34·40
−1135	= 43·31	− 956	= 40·20
−1123	= 39·76	− 947	= 45·66

This change brings the path of the eclipse −1235 rather too far south of Babylon, but leaves the eclipse −1217 still satisfying the observation. But now the eclipse of −1014 is brought within the limits necessary to satisfy the record, the central path of the eclipse passing within two degrees to the north of Babylon.

The date of this eclipse, −1014 July 11th, can be brought into accord with that recorded on the cuneiform Tablet if it be interpreted in the manner thought preferable by Mr. King, and a date assigned only from fifteen to thirty years earlier than the accession of the king Nabû-mukîn-apli. By adopting, in accordance with the revised view of Winckler, Hommel, Delitzsch, and Peiser, a date of about -995 ± 10 years for the accession of this king, the seventh year of Eulbar-shakin-shum would fall about -1014 ± 10 years, and the day, July 11th, is a very probable equivalent for the "twenty-sixth day of the month Sivan." Hence the date of this eclipse is in harmony with the record.

The path of this eclipse is—

East Longitude	38°	40°	42°	44°	46°	48°
North Latitude	37·2	36·3	35·4	34·5	33·6	32·8

But the sun sets at Babylon according to this data more than half an hour before the time of maximum eclipse, so that it would only be visible as a very large partial eclipse, which would not correspond to the record. To bring the maximum eclipse into visibility at Babylon the adopted value

of the moon's mean longitude must be increased by 0·32°, corresponding to an increase in the value of the secular acceleration in mean longitude of 1·48″, thus bringing it up from 6·18″ to 7·56″. But this would increase the latitude of the point where the path of the eclipse crossed the meridian of Babylon from 34·4° to over 38°, so that it would no longer correspond with the observed phenomenon. To bring the eclipse into accord with the recorded phenomena, it would be necessary to suppose the longitude of the moon's node to be also increased by double this amount, or its secular acceleration to be increased by about 3″, bringing its value up to about 9·5″, which is fully 2″ greater than can be deduced from the more modern observations.

The adopted theoretical elements of the moon's orbit, even when amended by increasing the secular motion of the perigee and node, does not represent the modern observations since 1660 with the closeness which is desirable. To enable these modern observations to be properly represented it is necessary to apply small corrections to nearly all the elements. The system of corrections which serves best to bring these observations into accord with the tables, if we suppose the theoretical value of the moon's secular acceleration in mean longitude to remain unchanged, is—

$\Delta l = -11{\cdot}6''\mathrm{T}$	$+0{\cdot}00''\mathrm{T}^2$	$+0{\cdot}0000''\mathrm{T}^3$
$\Delta A = +22{\cdot}5$	$+6{\cdot}36$	$+0{\cdot}0064$
$-\Delta B = +28{\cdot}8$	$+0{\cdot}77$	$-0{\cdot}0007$

but if the value of the secular acceleration in mean longitude be deduced directly from the observations, as well as the values of the other elements, then the system of corrections which best represents the observed places of the moon is—

$\Delta l = -12{\cdot}7''\mathrm{T}$	$+1{\cdot}25''\mathrm{T}^2$	$+0{\cdot}0012''\mathrm{T}^3$
$\Delta A = +22{\cdot}5$	$+6{\cdot}36$	$+0{\cdot}0064$
$-\Delta B = +40{\cdot}0$	$-0{\cdot}77$	$-0{\cdot}0007$

and the modern observations can be represented by any system of corrections lying between these two, and as far as these observations are concerned any such system may be regarded as permissible.

Professor Newcomb deduced the system of corrections—

$\Delta l = -10{\cdot}0''\mathrm{T}$	$+1{\cdot}77''\mathrm{T}^2$	$+0{\cdot}0015''\mathrm{T}^3$
$\Delta A = +11{\cdot}8$	$+0{\cdot}68$	$-0{\cdot}0055$
$-\Delta B = +23{\cdot}9$	$+0{\cdot}12$	$-0{\cdot}0003$

but this system depends on a very large empirical term of long period, for whose argument there can be no theoretical justification, and which fails to represent the observed values with sufficient closeness.

Another system has been deduced by Dr. Cowell from the observations

between 1750 and 1900, but it fails, likewise, to adequately represent the observations made between 1770 and 1870, and does not properly represent the earlier observations made prior to 1740. With sufficient approximation this system may be written as—

Δl	$= -18{\cdot}0''\mathrm{T}$	$+0{\cdot}04''\mathrm{T}^2$	$+0{\cdot}0070''\mathrm{T}^3$
ΔA	$= +10{\cdot}7$	$+5{\cdot}40$	$+0{\cdot}0020$
$-\Delta B$	$= +16{\cdot}9$	$-0{\cdot}51$	$+0{\cdot}0000$

Computing from these different systems the correction to the elements *l*, A, B for the epoch $-1100+\mathrm{T}$ centuries, there are obtained the values—

	Δl.	ΔB.	ΔA.
Nevill I.	$+0{\cdot}094^\circ - 0{\cdot}003^\circ\mathrm{T}$	$+0{\cdot}407^\circ - 0{\cdot}020^\circ\mathrm{T}$	$+1{\cdot}262^\circ - 0{\cdot}092^\circ\mathrm{T}$
Nevill II.	$+0{\cdot}387 - 0{\cdot}023$	$+0{\cdot}498 - 0{\cdot}023$	$+1{\cdot}262 - 0{\cdot}092$
Newcomb	$+0{\cdot}485 - 0{\cdot}030$	$+0{\cdot}163 - 0{\cdot}005$	$+0{\cdot}102 - 0{\cdot}012$
Cowell.....	$+0{\cdot}109 - 0{\cdot}001$	$+0{\cdot}253 - 0{\cdot}013$	$+1{\cdot}162 - 0{\cdot}083$

Employing these corrections, the latitude of the point where the path of central eclipse crosses the meridian of Babylon become—

Eclipse.		Nevill I.	Nevill II.	Newcomb.	Cowell.
-1235	Annular.....	$+23{\cdot}08^\circ$	$+14{\cdot}07^\circ$	$+17{\cdot}25^\circ$	$+24{\cdot}45^\circ$
-1217	Annular.....	30·18	32·97	37·22	30·44
-1210	Total	14·99	22·02	21·19	14·31
-1163	Annular.....	25·20	25·13	27·03	26·08
-1135	Annular.....	46·76	51·22	50·48	45·65
-1123	Total	38·72	36·03	36·62	39·40
-1116	Total	24·56	24·49	22·47	23·75
-1069	Total	14·76	9·21	9·23	15·35
-1062	Total	37·29	36·95	35·76	36·74
-1014	Annular.....	34·81	37·50	40·78	36·10
-956	Total	38·38	30·84	30·64	39·37
-947	Total	46·98	42·71	37·01	45·39

It is obvious that the four eclipses, -1210, -1135, -1069, and -947, can be neglected, as they cannot be brought into accord with the recorded observation without very large alterations in the lunar elements, for which there is no justification.

The eclipse of -1235 can also be neglected if the purely theoretical data be replaced by any derived from the observations, as all these throw the path of the eclipse far to the south of Babylon. The path of the eclipse of -1163 passes too far to the south of Babylon, and can only be brought centrally over the city by decreasing the secular acceleration of the moon's node by $5''$, which is impossible; whilst the path of the eclipse of -1116 can only be brought centrally over Babylon by increasing the secular acceleration of the moon's node by about $7''$, which is also impossible.

Considering the other eclipses :—

Eclipse of −1217, June 5th. The path of this eclipse can be brought centrally over Babylon by a possible system of corrections intermediate between Nevill I. and Nevill II., with the time of central eclipse about half an hour before sunset. Under these conditions the eclipse agrees well with the phenomena recorded at Babylon as occurring in the seventh year of the king Merodach-Baladin I. or the seventh year of the king Adad-shum-utsur, according as the beginning of the reign of the king Nabû-mukîn-apli be placed in −1027 or −994, in accordance with Sayce or Winckler.

Eclipse of −1123 May 18th. This eclipse is total in the early afternoon, and according to the data Nevill II. derived direct from the observations, the path of central totality would pass about 3½° to the north of Babylon, and would have a width of about a degree and a half. Hence to make it total at Babylon the secular acceleration of the moon would have to be increased by about a second of arc, and the secular acceleration of the moon's node by about half as much, with small consequential changes in the secular motions of each element. These are quite possible changes which would bring the secular acceleration of the mean longitude to about +8·4″, and that of the node to about +7·8″.

Under these conditions the path of central totality would be—

East Longitude	38°	40°	42°	44°	46°	48°
North Latitude	31·5	32·1	32·6	33·1	33·5	33·8

The year −1123 would correspond to the seventh year of the king Marduk-nadin-akhi, who reigned for twenty years, by assigning the accession of King Nabû-mukîn-apli to the year −1018, or to the seventh year of Nebuchadresser I., who reigned for thirteen years, if the accession of Nabû-mukîn-apli be placed in −1000. The day, May 18th, is very early for the 26th day of Sivan, but possible on the assumption of the very late intercalation of a month.

Eclipse of −1062 July 31st. On all four systems of correction the central line of totality of this eclipse passes from 3° to 6° to the north of Babylon, with a width of shadow rather greater than a degree, and it can only be made total at Babylon, and so brought into harmony with the observed record by increasing the secular acceleration of the moon's mean longitude from +6·2″ to +11·0″, or by decreasing the secular acceleration of the moon's node from +6·5″ to +2·0″, which is impossible according to theory. The year is probable, but the day, July 31st, cannot be reconciled with the "twenty-sixth day of the month Sivan," being more than a fortnight later than the latest day.

Eclipse of −1014 July 11th. The central line of this eclipse passes from 2° to 5° to the north of Babylon, according to Nevill's and Cowell's

data, and is thrown right to the north by Newcomb's data, and in all cases does not reach its greatest phase until after sunset.

Eclipse of −956 May 31st. According to the systems of correction Nevill I. and Cowell, the shadow of this eclipse passes from 5° to 7° north of Babylon, but according to the systems Nevill II. and Newcomb it passes 2° to the south of Babylon. Hence a permissible system of corrections intermediate between the systems Nevill I. and Nevill II. can be deduced, which will make this eclipse total at Babylon, it being only necessary to reduce the assumed value of the secular acceleration in mean longitude from +7·43″ of Nevill II. to +7·10″. The day of the eclipse, May 31st, though early, is a possible date for the twenty-sixth Sivan; but the year −956 presents difficulties, for Marquart and Lehmann-Haupt alone of all authorities would place the seventh year of Eulbar-shakinshum at so late a date as this, nearly all the others placing it from forty to eighty years earlier.

From these results it would appear that the only eclipses which can be held to correspond with the eclipse of the sun supposed to have been recorded at Babylon on the cuneiform Tablet No. 35968 are these occurring on—

−1217	June 5th
−1123	May 18th
− 956	May 31st

and of these three, that corresponding best with the theory and observation is that of −1217 June 5th.

So far it has been supposed that the data for the secular motion of the sun in mean longitude employed in the adopted solar tables requires no amendment, so that $\Delta l'$ may be regarded as zero. But if it be supposed that the motion of the sun may be undergoing an apparent secular acceleration; either a true acceleration due to a gradual increase in the mass of the sun, or a gradual change in its figure, or to the effect of a resisting medium; or an apparent acceleration due to a gradual increase in the length of the day arising from the effects of tidal friction on the rotation of the earth; then by such a change it is possible that other of the above eclipses may have been total at Babylon.

Dr. Cowell assumes that the adopted theoretical expression for the mean longitude of the sun requires a correction of $+4{\cdot}09''T^2$, and the corresponding expression for the mean longitude of the moon requires an additional correction of $+4{\cdot}69''T^2$. Under these conditions the eclipse of −1062 July 31st, becomes total at Babylon, though it does not satisfactorily comply with the record owing to the day, July 31st, being too late to accord with the twenty-sixth day of Sivan of the record. A still smaller correction of $\Delta l' = +2{\cdot}5''$ would render the eclipse of −1069

June 20th total at Babylon, and the day, June 20th, accords well with the day recorded on the Tablet.

There would be no justification for introducing so important a change into the expression for the mean longitude of the sun merely to satisfy the record of a single eclipse of the sun, however important this record might be, and this eclipse seen near Babylon is of the highest importance.

Dr. Cowell justifies his proposal to introduce this secular acceleration in the apparent motion of the sun by the fact that by so doing he can bring the amended tables into accord with the modern observations of the sun and moon, and at the same time make them closely represent the recorded ancient eclipses of—

−1062	July 31st	Assumed Eclipse of Babylon
− 762	May 18th	The Eclipse of Nineveh
− 602	May 18th	The Eclipse of Larissa
− 584	May 28th	The Eclipse of Thales
− 430	August 3rd	The Eclipse of Thucydides
− 309	August 15th	The Eclipse of Agathocles
+ 197	June 3rd	The Eclipse of Utica

And if the principal ancient eclipses of the sun can be represented by no other hypothesis, this would constitute strong evidence.

But is this the only hypothesis which will serve to represent the principal ancient eclipses as well as the modern observations of the sun and moon? Further, can it be adopted without raising serious theoretical difficulties in other directions? The consideration of these questions must be deferred for the present.

This eclipse of Babylon is likely to be of the greatest value, as it may serve as a criterion to distinguish between the different possible systems of corrections to the elements of the moon and sun by which the series of ancient eclipses of the sun may be represented.

If it be identified with the eclipse of −1062 July 31st, a system of correction similar to that proposed by Dr. Cowell would be established, with all its momentous consequences. If identified with the eclipse of −1123 May 18th, then by slight modification of a system of corrections analogous to those of Professor Oppolzer, it would be possible to represent also the eclipses of −762 June 15th, −602 May 18th, −584 May 28th, −309 August 15th, −173 October 20th, −128 November 20th, and +197 June 3rd: or eight of the best established ancient eclipses. If identified with the eclipse of −1217 June 5th, the eclipses of −762, −602, −430, −309, −173, and −128, could be represented by data agreeing closely with that furnished by theory. If identified with the eclipse of −1014 July 11th, a corresponding system of data would represent almost the same series of eclipses.

Hence the astronomical importance of the identification of this eclipse —an identification which would also prove of great value in settling the doubtful chronology of the earlier kings of Babylon. It is much to be hoped, therefore, that a more perfect copy of this cuneiform Tablet may be found amongst the great mass of such Tablets stored in the different Museums, or else the occurrence of this eclipse be found recorded on one of the historical Tablets.

OBSERVATIONS ON THE INHERITANCE OF CHARACTERS IN *ZEA MAYS* LINN.

By J. Burtt-Davy, F.R.S.S.Af., F.L.S., F.R.G.S.

(Read May 17, 1911.)

I.

SEGREGATION OF TWO PAIRS OF CHARACTERS IN A CROSS-BRED MAIZE EAR.

The following statistical study of ear number 1157 has been made this season in the course of an investigation into the inheritance of characters in the maize plant (*Zea mays*). This ear was grown from a red flint grain of ear 1027; it has 12 rows of grain, which is red, white, or yellow in colour, and of the flint and sugar types. It was hand pollinated with pollen from other red-grain plants grown from ear 1027. The white grains are of a clear, pure white, without the least tendency to shade into red.

The following is a summary of the number of grains of each type in each row:—

	Table 1.			Table 2.			Table 3.				
Row.	Red.	White.	Total.	Flint.	Sugar.	Total.	Red Flint.	White Flint.	Red Sugar.	White Sugar.	Total.
1	22	9	31	22	9	31	15	7	7	2	31
2	26	7	33	22	11	33	16	6	10	1	33
3	26	6	32	21	11	32	18	3	8	3	32
4	21	10	31	26	5	31	17	9	4	1	31
5	20	12	32	24	8	32	16	8	4	4	32
6	23	8	31	23	8	31	19	4	4	4	31
7	25	7	32	23	9	32	19	4	6	3	32
8	19	11	30	23	7	30	14	9	5	2	30
9	21	8	29	21	8	29	14	7	7	1	29
10	24	7	31	23	8	31	18	5	6	2	31
11	26	4	30	23	7	30	19	4	7	0	30
12	21	10	31	24	7	31	17	7	4	3	31
Total ...	274	99	373	275	98	373	202	73	72	26	373
Average per row	23	8·25	31	23	8	31	17	6	6	2	31
Per cent.	73·45	26·55	—	73·73	26·27	—	54·16	19·57	19·30	6·97	—

Yellow colouring matter.—There are a few yellow grains on the ear, which are due to stray pollen from adjacent rows of yellow maize which have either mixed with the "red" pollen when the latter was being collected, or have gained access to the silks when the bag was removed for the purpose of hand-pollination. When the "yellow" pollen has fallen on to a "white" ovule it has produced a clear yellow grain; when it has reached a "red" ovule, the grain distinctly shows a mixture of red and yellow. There is thus no difficulty in distinguishing between red and non-red grains. Though not so pronounced in the sugar grains, the yellow colouring matter is quite distinguishable in contrast with the horny appearance of an ordinary "white" sugar grain.

Red colouring matter.—Table 1 shows clearly that in this case red is dominant over white. Where both red and yellow meet in the same grain, both colours appear (as is to be expected, red and yellow not being opposing characters), but the red is more conspicuous than the yellow; there is not any blending of colours such as occurs when blue and yellow meet in the same grain and produce green. The red colouring matter here discussed appears not to be confined to the pericarp, as is the case with the red colouring matter of "Red Cuzco" and some of the red strains frequently met with in fields of supposedly pure white maize; consequently it is transmitted differently. A separate experiment, also conducted this season, shows that the particular colour here dealt with is transmitted with the pollen, producing a red grain as the immediate result of the application of pollen of a red strain to the ovules of a white breed. There is considerable variation in the degree of redness in both dent and sugar grains, but there is no shading off into white such as is often the case with crosses between yellow and white.

Indentation.—The starchy (*i.e.*, non-sugary) grains are slightly indented; this was puzzling for a time, as the parent grains were red flints. Subsequently, however, one of the most vigorous plants in the row was found to have developed a red dent ear, and it is probable that the pollen from this plant caused the slight indentation in what would otherwise be flint grains.

Half-sugar Grain.—One grain is of particular interest because one half shows the sugar character and the other half the ordinary starch or "dent" character.

Percentages.—The percentages of each of the four types of grain obtained through the re-combination of the two pairs of characters, *i.e.*, redness and whiteness with dentness and sugariness, is interesting and instructive. The figures in Tables 1 and 2 show that both dentness and redness are dominant, while sugariness and whiteness are recessive.

The actual percentages occurring on this ear are summarised from Table 3 as follows:—

$$\left.\begin{array}{l}\text{Red}\left\{\begin{array}{ll}\text{Dent} & \ldots\ldots\ldots\ 54{\cdot}16\% \\ \text{Sugar} & \ldots\ldots\ldots\ 19{\cdot}57\end{array}\right\} = 73{\cdot}73\% \\ \text{White}\left\{\begin{array}{ll}\text{Dent} & \ldots\ldots\ldots\ 19{\cdot}30\% \\ \text{Sugar} & \ldots\ldots\ldots\ 6{\cdot}97\end{array}\right\} = 26{\cdot}27\%\end{array}\right\} = 100\%$$

We should expect to find approximately the following proportions of each combination :—

	Red Grains.	White Grains.
Dent grains	75% of 75% = 56·25%	and 75% of 25% = 18·75%
Sugar grains	25% of 75% = 18·75%	and 25% of 25% = 6·25%

or—

$$\left.\begin{array}{l}\text{Red}\left\{\begin{array}{ll}\text{Dent} & \ldots\ldots\ldots\ 56{\cdot}25\% \\ \text{Sugar} & \ldots\ldots\ldots\ 18{\cdot}75\end{array}\right\} = 75\% \\ \text{White}\left\{\begin{array}{ll}\text{Dent} & \ldots\ldots\ldots\ 18{\cdot}75\% \\ \text{Sugar} & \ldots\ldots\ldots\ 6{\cdot}25\end{array}\right\} = 25\%\end{array}\right\} = 100\%$$

For such a small total number of grains (373) the actual figures are remarkably close to the expected, and sufficiently so to be of practical use to the breeder.

II.

ROW-NUMBERS IN MAIZE EARS.

It is well known among maize-growers that the number of rows of grain on an ear of maize varies from 8 to 24 or even more, according to the breed ; also that in the same breed the number may vary within certain limits, *e.g.*, 8, 10 or 12 in some breeds, 12, 14, 16 or 18 in others, and 18, 20, 22 or 24 in yet others. In some breeds the range of variation is even greater than this, while in others it seems to be more closely limited. In some breeds an ear carrying more than 8 rows is considered untrue to type, but I am not aware that any South African grower has yet succeeded in fixing the number of rows in any breed so that no variation occurs in that respect. In the course of a series of breeding experiments which are not yet complete, I have met with the following interesting case :—

Thirty-three plants of Arcadia sugar-maize each of which bore two well-developed ears, were studied as regards number of rows. On 21 plants the number on the upper ear was different from that on the lower, while on 12 plants the number was the same on each ear. Of the 21 plants of which the number of rows differed on the two ears, 13 had a larger number on the lower than on the upper, while 8 had a smaller number on the lower than on the upper. The distribution of rows was as follows :—

ARCADIA SUGAR-MAIZE.

Plants with 2 ears.

Plant No.	Upper Ear.	Lower Ear.
1	8	12
2	10	10
3	10	14
4	10	12
5	12	12
6	10	8
7	10	8
8	10	12
9	12	12
10	8	10
11	8	12
12	12	12
13	12	12
14	10	12
15	12	12
16	12	12
17	12	12
18	12	10
19	12	14
20	10	12
21	8	10
22	10	10
23	10	8
24	12	10
25	8	12
26	12	12
27	12	10
28	12	10
29	10	10
30	8	10
31	10	12
32 3 ears.	upper no grain. middle 8	8
33	10	12

Class.	Upper Ear.	Lower Ear.	Number of Plants.	Number of Plants in each Class.
As many rows in lower as in upper	12	12	8	12
	10	10	3	
	8	8	1	
More rows in lower than in upper ...	10	14	1	13
	10	12	6	
	8	12	3	
	8	10	3	
Fewer rows in lower than in upper	12	14	1	8
	12	10	4	
	10	8	3	

Summary.

Upper Ear.	Lower Ear.	Number of Plants.
8	8	1
	10	3
	12	3
10	8	3
	10	3
	12	6
	14	1
12	8	0
	10	4
	12	8
	14	1
—	—	Total 33

The total number of ears producing any given number of rows is as follows :—

Rows.	Ears.
8	11
10	23
12	30
14	2
—	Total 66

The "Arcadia" is a white sugar-maize obtained as a cross between a normally 8-rowed "Black Mexican" and a white flour corn normally bearing a larger number of rows, but it is not known whether either was pure bred for row-numbers and no subsequent selection in this line has been made.

It is generally supposed by maize-growers, in this country at any rate, that the number of rows is a definite, heritable character. Results obtained by crossing two other breeds, viz., an 8-row and an 18-row (believed to be pure as regards this character) have this year produced intermediates in the F.1 generation. The case described above seems to indicate that the development of rows is within certain limits a vegetative character, depending in part on seasonal conditions and on food supply. This view is strengthened by the fact that this is the first year in which I

have noticed 14-row ears in this breed, all the parent ears for two or three generations having been 8-, 10-, or 12-rowed.

At the same time there is ample indication that within certain limits row-numbers are inherited in the maize plant, but it is doubtful whether any strains grown in South Africa are sufficiently pure bred for this character, to demonstrate the point with absolute certainty.

III.

INHERITANCE OF ROW-NUMBERS IN CROSS-BRED MAIZE.

The following is an advance note on the result of crossing an 8-rowed white dent maize ♀ (No. 904) with an 18-row yellow dent ♂ (No. 905) and of the reciprocal cross. Difficulty having been experienced in obtaining in South Africa any breeds of maize pure as regards row-numbers, I approached the United States Department of Agriculture, and with its kind assistance was enabled to obtain in 1909 what I required; both types bred true, and the cross and reciprocal cross were made in the season 1909–10.

White dent 8-*row* ♀ × *Yellow dent* 18-*row* ♂.—The ears produced as the direct result of cross-pollination bore all the visible characters of the mother plant, differing only in the cross-bred grain being yellow with a white cap.

Yellow dent 18-*row* ♀ × *White dent* 8-*row* ♂.—The ears produced as the direct result of cross-pollination bore the visible characters of the mother plant, differing only in the cross-bred grain having a white or light-yellow cap.

The F.1 generation.—The heterozygous grains obtained in 1909–10 were planted in the early part of the season 1910–11. Fifty-two plants were grown; these were carefully hand-pollinated with pollen from plants bearing the same record-number, *i.e.*, of the same parentage. The technique employed was to cover the ears with a loose paper bag, tied at the neck, as soon as the "silks" appeared. Pollen was collected by pulling the tassel, keeping the same overnight in a jug of water in a room free from draught, and during the succeeding three days collecting in a seed-envelope the pollen which fell on to a newspaper placed beneath for the purpose. To apply the pollen the bag was removed and sufficient pollen shaken on to the silks; the process was repeated twice, at intervals of seven to ten days, fresh pollen being collected for each operation. This usually resulted in the production of well-developed ears.

Thirteen plants were destroyed by stalk-borer, wind-storm or accident; leaving thirty-nine ears to be dealt with.

Explanation of Record-numbers.—The following record-numbers are used in the tables:—

1063	ex 905 (18-row ♀) × 904 (8-row ♂)	Yellow grain with light yellow caps.
1064	„ do. do.	Yellow grain with white caps.
1066	„ 904 (8-row ♀) × 905 (18-row ♂)	do.
1067	„ do. do.	do.
1068	„ do. do.	do.

Effect of Reciprocal Cross.—Separating the two crosses, we have the following figures:—

18-*row* ♀ × 8-*row* ♂.

Parent Ear No.	Rows. 8.	10.	12.	14.	16.	Total Ears.
1063	0	1	4	2	1	8
1064	0	2	4	0	0	6
Total.....	0	3	8	2	1	14
Per cent.	0	21·4	57·1	14·3	7·2	= 100

8-*row* ♀ × 18-*row* ♂.

Parent Ear No.	Rows. 8.	10.	12.	14.	16.	Total Ears.
1066	1	2	3	1	0	7
1067	0	2	4	3	0	9
1068	1	0	3	5	0	9
Total.....	2	4	10	9	0	25
Per cent.	8	16	40	36	0	100

Summary.

Parent Ear No.	Rows. 8.	10.	12.	14.	16.	Total Ears.
18 × 8	0	3	8	2	1	14
8 × 18	2	4	10	9	0	25
Total.....	2	7	18	11	1	39
Per cent.	5·1	18·1	46·2	28·2	2·6	100

Row-numbers as Fluctuating Variations.—The range of variation in the progeny, from 8 to 16 rows, is probably due in part to fluctuating variation such as is always met with in the maize plant, as for instance in the case of a 20-row ear produced by a pure-bred 18-row plant, and as in the case of plants which produce both 8-row and 10-row ears on the same plant. That this variation is partially dependent on conditions of growth is indicated by the frequent occurrence of ears bearing a pair of rows more in the lower half than in the upper; this seems to be especially prevalent in seasons which cause a check in growth. This season, which was dry during the early summer and wet towards the end, ears have been found with a pair of rows more in the upper part of the ear than in the lower. But the fluctuating variation in row-numbers appears to be limited, *e.g.*, an 8-row type shows fluctuating variation down to 4-rows on one side and up to 12-rows on the other side; I have met with a few cases of 14-row ears in a normally 8-row breed, but am inclined to think this may have been due to crossing. On the other hand, an 18-row breed may vary to 24-rows on one side and down to 14 on the other, but I doubt whether it ranges below 12.

Conclusions.—The cross between an 8-row and an 18-row breed results in the production of an intermediate form in the F.1 generation. Of the 39 cross-bred ears under consideration only two produced the same number of rows as either parent, while nearly 75 per cent. produced either 12 or 14 rows; as regards these two row-numbers, the cross and the reciprocal cross produced nearly the same proportions, the 18-row × 8-row giving 71·5 per cent., and the 8-row × 12-row 76 per cent.

It is intended to continue this investigation next year, and to record the splitting out in a large number of individuals, especially of the 10-, 12-, and 14-row ears.

IV.

NOTE ON INHERITANCE OF COB-COLOUR IN MAIZE.

A cross and reciprocal cross made between a white-cobbed, white-grained breed of maize (Hickory King) and a red-cobbed, yellow-grained breed has resulted in the production in the first filial generation of all red-cob ears. This experiment will be continued next year to determine the percentages of red and of white cobs which will reappear. This is of some importance to the maize-breeder, for red cobs are becoming too prevalent in white-grained breeds, to the detriment of the grain.

SUMMARY.

In "Red Cuzco" and some other breeds of red maize the red colouring matter is confined to the pericarp; being therefore a fruit character and not a seed character, it does not appear in the ear immediately resulting from a direct cross between a white ♀ and a red ♂.

In a red dent breed under investigation the red pigment occurs in the aleurone layer, and not in the pericarp. Being a seed character it is transmitted directly by the pollen grain to the ovule of a white breed. It behaves as a dominant to whiteness; where it meets yellowness in the same grain it is more conspicuous than yellow. The writer has not met with a previous record of the occurrence of a red pigment of this character in the aleurone layer of the maize grain.

When this red dent is crossed with a white sugar breed, the segregation in the second generation of the two pairs of characters, redness *v.* whiteness and starchiness *v.* sugariness, is in approximately the following proportions:—

Red	Starchy	56·25	= 75%
	Sugary	18·75	
White	Starchy	18·75	= 25%
	Sugary	6·25	

In other words—

	Red Grains.		White Grains.
Starchy grains 75% of 75%	= 56·25%	and of 25%	= 18·75%
Sugary grains 25% of 75%	= 18·75%	and of 25%	= 6·25%
	75·00%		25·00%

A single grain has been found on the ear studied, which distinctly shows the starchy character in one half and the sugary character in the other—a very unusual feature.

A study of row-numbers in maize ears indicates that within certain limits the number of rows of grain on an ear is subject to fluctuating variation, which may perhaps be affected by season or food-supply, or both. In more than 20 plants of Arcadia Sugar-maize studied this year, each of which produced two ears on one stalk, the uppermost ear has had a different number of rows from that of the lower ear. On 13 plants the largest number of rows occurred on the lower ear, while on 8 plants the largest number was on the upper ear. In 12 plants of two ears the row-numbers were the same on both. In one case there were 4 more rows on one ear than on the other. Several plants of Hickory King bearing two ears, have also produced different numbers of rows on the two ears.

The range of variation appears to be limited, however; a normally 8-rowed type ranges between 4 and 14 rows, while a normally 18-rowed type ranges between 12 and 24 rows.

The result of crossing an 8-row with an 18-row type of maize is to produce an intermediate type in the first generation; both 8-row and 18-row types practically disappear in the heterozygous form. The intermediate type bears mostly 10, 12, or 14 rows, the 12-row type greatly predominating. The experiment will be continued next year to determine the proportion of the 8-row and 18-row types which reappear. The ears produced by the cross and the reciprocal cross are indistinguishable.

A white-cobbed breed crossed with a red-cobbed produces a red cob in the first filial generation, and so does the reciprocal cross.

THE SPECTRUM OF THE RUBY—PART II.—AND THE ARTIFICIAL RUBY.

BY JAMES MOIR, M.A., D.Sc., F.C.S., F.R.S.S.Af.

In Part I. (Trans. R. S. S. Afr., I. [2], 321) an account was given of the extraordinary spectrum of this gem, as seen with a small spectroscope. The ruby spectrum has now been thoroughly examined with good instruments (kindly lent me by the South African School of Mines and Technology, Johannesburg). In all, eight absorption lines have been discovered in the spectrum, and all of these are of unusual narrowness, so that the spectrum is possibly the most remarkable of all known absorption spectra, being comparable only with those of neodymium and of reduced uranium solutions.

The first three of these hair-lines constitute the system near B, described in Part I. The red transmission line has been found to be double, and is caused by the existence of two deep but narrow absorption bands (previously given as limited by λλ6915 and 6945), with a hair-line absorption band almost exactly between them. The first absorption band has its sharp inner limiting edge at λ6955 (diffraction instrument) or λ6956 (Hilger's direct). It is a very deep band, shading off towards the infra-red as far as the *a* line. The second band (hair-line in centre of transmission) goes from λ6942 to λ6947 when observed with the narrowest possible slit and sunlight. With an ordinary slit it is invisible. The third resembles the first, but its sharp edge faces the infra-red, and it shades off towards the B line: the sharp edge with narrowest slit is at λ6933 ± 1. The measurement is difficult and requires concentrated sunlight: with an ordinary slit the margin of illumination is at about λ6920, as stated in Part I.

The other five lines are more easily observed in the artificial ruby, which gives exactly the same spectrum as the natural gem, but in an exaggerated form on account of its superior size and depth of colour. Only approximate measurements are possible. Line No. 4 is exceedingly faint and goes from about λ6760 to λ6790. Line No. 5 is near C, about $\frac{1}{10}$ of the distance therefrom towards B (λ6610 ± 10).

The other three bands are strong and situated in the blue: Nos. 6 and 7 form an equal narrow pair at λ4775 and λ4760 (approx.) respectively.

No. 8 is broader than 6 or 7 and absorbs from λ4690 to λ4680. These last three lines resemble those of indium.

The most curious thing about the ruby spectrum is that none of the lines can be definitely identified with those of any known colouring matter. The colour is due to an inorganic cause, as the ruby can be ignited without alteration. It is independent of the anisotropic structure also, since the natural variety occurring in nearly isotropic hexagonal plates shows the same spectrum. Hair-lines of this character occur only in erbium and "didymium" solutions, but none of the latter agree with the ruby lines.

The cause of the dichroism of ruby has been discovered by the author. When the gem (best an artificial one cut with two parallel faces) is examined with nicol and spectroscope, there is seen, in addition to the hair-line spectrum above described, a broad band in the green, which appears and disappears as the gem is rotated. The pink-violet stage is the one of deep absorption and the yellowish stage that of little absorption.

As the artificial ruby is said to be coloured with chromium, the author has examined the spectrum of most of the typical chromium compounds. The following have no sharp lines in their spectrum: $KCr(SO_4)_2$ (either solution or solid), $Cr_2(SO_4)_3$ (solid scales), Cr in beads of either borax or of $NaPO_3$, K_3CrCy_6 in solution.

On the other hand, a diffuse narrow line at about λ6960 ± 10 was seen in the spectrum of a strong solution of potassium chrom-oxalate $K_3Cr(CO_2)_6$, which agrees in position though not in character, with the first ruby line. The other ruby lines are completely absent; nevertheless, the coloration of ruby may possibly be due to chromium, the vibrations of the element being modified by its imprisonment in an anisotropic medium.

2. NOTES ON THE SPECTRA OF THE PRECIOUS EMERALD AND OTHER GEM-STONES.

By James Moir, M.A., D.Sc., F.C.S., F.R.S.S.Af.

The spectrum of the true emerald consists of a broad pure-green transmission with three (new) very difficult hair-lines in the red. These are (*a*) and (*b*), a close pair near B, on the other side from the ruby-complex, *i.e.*, facing C: the approximate wave-lengths are λλ6805 and 6795; and (*c*) at about λ6330 (very faint). There is also a very hazy wider band between these, round about C.

The spectrum of Cr_2O_3 in a borax-bead contains a hazy band with a fairly sharp edge at λ6800, so that the colour of emerald may be due to chromium: chromium glass does not show this band, nor do beads of vanadium or uranium show anything. Chromium acetate solution shows a similar band, but slightly displaced towards the yellow.

The artificial emerald and the sapphire, either natural or artificial, have no hair-lines in their spectra. This is true also of the following coloured minerals which were examined: Rubellite, red spinel, amethyst, purple fluorspar, blue aquamarine, rose quartz, lepidolite, and topaz, and also purple titanium beads. Blue-green spinel has a broad band in the violet at about λ4550 to λ4600. The artificial emerald is merely a green sapphire (probably coloured with iron as well as titanium), and can thus be easily distinguished from the real emerald: wheras at present there is no satisfactory criterion between natural and artificial sapphires or rubies.

The well-known almandine spectrum has been measured, as the wave-lengths do not seem to have been published: (*a*) Very faint, about λ6150; (*b*) strong, λ5750; (*c*) broad, about λ5300; (*d*) strongest, λ5070 to 5050; and (*e*) very faint and broad, about λ4600.

A NOTE ON THE PRINCIPAL SYSTEMATIC WORK AND PUBLICATIONS DEALING WITH THE SOUTH AFRICAN PROTEACEÆ.

By E. P. Phillips, M.A.

(Read June 21, 1911.)

The Natural Order Proteaceæ is a large group of plants almost exclusively confined to the Southern Hemisphere, being found in Australia, Brazil, Chili, Guiana, New Caledonia, New Zealand, South Africa, Tasmania, but also found in Tropical America and Tropical Africa. The Order is most abundantly represented in Australia and South Africa, but no genus or species is native of both countries; species of *Hakea* and *Grevellia*, however, are cultivated at the Cape, and certain genera, *e.g.*, *Lomatia* and *Orites*, have representatives in both Australia and Chili.

The South African section of the Order, with perhaps the exception of *Brabieum stellatifolium*, Linn., forms a very natural group of plants, and very early attracted the attention, not only of the early botanical collectors, but also of the early navigators by their singular beauty and diversity of form. In 1605 C. Clusius * figures a capitulum of *Protea neriifolia*, which he states was brought from Antolgil Bay, on the east coast of Madagascar, in the year 1597. This locality is evidently an error, as the genus *Protea* is entirely absent from Madagascar, the specimen must have been collected round the slopes of Table Mountain. The above reference and figure is the earliest we have of a member of the Order from South Africa. Leonard Plukenet † figures the Silver Tree (*Leucadendron argenteum*, Linn.), and again in 1696 ‡ makes a reference to "Leucadendros Africana arbor, &c.," and refers back to the figure in the Phytographica. (The reference to Zanon, "Arbor ferens folia argentea," appears to be to an Indian plant and not to *Leucadendron argenteum*.) Plukenet mentions this plant as having been sent from the Cape by Patric Adair, who must therefore have been one of the first Cape botanical collectors. Prior to the year 1700 many Proteaceæ, together with other Cape plants, were sent to the Gardens of Holland by the early Dutch settlers, as Jacob

* C. Clusius, "Exoticorum Liber Primus," 1605, p. 39.
† L. Plukenet, "Phytographica," 1691, t. 200, fig. 1.
‡ Ibid., "Almagestum Botanicum," 1696, p. 212.

Breyne * states that he received a dried specimen of "Frutex æthiopicum conifer, foliis cneori salici æmulus" (our Silver Tree), from Dr. Huybert in 1644 and from Dr. Slade in 1670, these men evidently being in charge of some of the Gardens of that period.

The first important collector sent to the Cape was Francis Masson (1772–73). Being commissioned by Kew, he made an extensive collection of Proteaceæ, many of which now constitute types of Robert Brown's species. Masson was followed by James Niven (1798–1803) as a collector for George Hibbert and the Empress Josephine. Most of his collectings were cultivated in the former's garden at Clapham, and formed the material on which Salisbury, Hibbert's gardener, worked. It is not quite within the scope of this paper to give a list of the collectors following Niven, but reference must be made to Drège, Ecklon, Ludwig, and Zeyher, whose large collections of Proteaceæ enabled Dr. Meisner to make a detailed study of the South African material. Passing mention may be made to the many species collected by the older botanists and still preserved in European herbaria which have not been found since, either having become extinct, or, as is also probably the case, the localities of many species are very restricted, and former hunting grounds have not been revisited by modern collectors. The writer finds this strikingly illustrated in the genus *Sorocephalus*, in which 10 out of the 13 species are only known from type specimens, mostly of Niven's collecting. Many interesting discoveries of long-lost species, however, have been made. *Serruria florida*, Kn., first collected by Thunberg on the French Hoek Mountains, was found again in 1891 by the late Dr. MacOwan; *Protea calocephala*, Meisn., sent to Europe over seventy years ago by Baron von Ludwig, was collected by Dr. J. Muir in the Riversdale District last year; *Protea caffra*, Meisn., last collected by Ecklon and Zeyher on the Magalisberg, was again found by Mrs. Dieterlen near Leribe, Basutoland, in 1910; *Protea neriifolia*, R. Br., was figured in the *Botanical Register* † and recorded from the Cape Peninsula; Dr. MacOwan was the first to rediscover it on the Peninsula in 1881, and the writer found a single plant of this species near Platteklip in April, 1910. It is to be hoped that many more of these lost or little-known species will yet be collected, so as to more fully complete our knowledge of this interesting Order.

The first important systematic publication on the Cape Proteaceæ appeared in 1720, by Hermann Boerhaave,‡ containing excellent woodcuts of 23 species. Boerhaave divided the Order into the three genera, *Lepi-*

* Jacob Breyne, "Exoticarum, Centuria Prima," 1678.

† *Botanical Register*, t. 208.

‡ H. Boerhaave, "Index Alter Plantarum quæ in Horto Academico Lugduno-Batavo aluntur," 1720.

docarpodendron, *Conocarpodendron*, and *Hypophyllocarpodendron*, composed as follows :—

Lepidocarpodendron contains 10 species of *Protea*, 1 species of *Aulax* (?), 1 species of *Mimetes*.
Conocarpodendron contains 7 species of *Leucadendron*, 1 species of *Protea*, 1 species of *Leucospermum*.
Hypophyllocarpodendron contains 2 species of *Mimetes*.

It will be important to bear in mind the composition of Boerhaave's genera when dealing with the works of Linnæus. The first collection of coloured plates of Proteaceæ appeared in 1745, by Weinmann,* who only recognised one genus, which he called *Scolymocephalus*, and in which he included species of *Protea*, *Leucospermum*, and *Leucadendron*. Between the years 1735 and 1774 appeared the various works of Linnæus, important as introducing the binomial system of nomenclature, but also important from our point of view, as he deals with the Proteaceæ in his Class Tetrangia Monogynia, and was the first author to use the name *Protea*. That Linnæus could not come to a definite conclusion as to the limits of the two genera *Protea* and *Leucadendron* is clearly evidenced in his works if his descriptions and references to Boerhaave's figures are compared, and it may not be out of place to state his views in their chronological order so far as I have been able to determine them.

For the sake of brevity we will denote the genera as follows :—

Conocarpodendron = A.
Hypophyllocarpodendron = B.
Lepidocarpodendron = C.

1. 1735 Syst. Veg. *Protea* = A, B, C.
2. 1735 Hortus Cliffortianus *Protea* = A, B, C.
3. 1737 Genera Plantarum *Protea* = B, C, not A.
4. 1738 Classes Plantarum *Protea* = C.
   Leucadendron = A.
5. 1742 Gen. Pl. *Protea* = A (partly).
   Leucadendron = A (partly), B, C.
6. 1753 Sp. Pl. *Protea* = A (partly).
   Leucadendron = A (partly), B, C.
7. 1754 Gen. Pl. *Protea* = A.
   Leucadendron = B, C.
8. 1759 Syst. Veg. *Protea* = A (partly).
   Leucadendron = A (partly), B, C.
9. 1762 Sp. Pl. *Protea* = A (partly).
   Leucadendron = A (partly), B, C.

* Weinmann, "Phytonthoza-Iconographia," 1745.

10. 1764 Sp. Pl. *Protea* = A (partly).
Leucadendron = A (partly), B, C.
11. 1767 Syst. Nat. *Protea* = A (partly).
Leucadendron = A (partly), B, C.
12. 1770 Syst. Nat. *Protea* = A (partly).
Leucadendron = A (partly), B, C.
13. 1771 Mantissa *Protea* = A, B, C, plus *Leucadendron.*
14. 1774 *Protea* = A, B, C, plus *Leucadendron* and *Aulax.*
15. 1778 Gen. Pl. *Protea* = A, B, C, plus *Leucadendron.*

For further details the reader is referred to an excellent account by Robert Brown * in the preface to his Essay, where the following summary will be found :—

1. He gave the genus *Protea* the same extent which he at length assigned to it in the Mantissa.
2. He limited it, leaving unnoticed that part to which at a later period he exclusively applied to the name.
3. He resumed his first opinions.
4. He subdivided it into two genera, giving them the same names which are adopted in the present Essay (*i.e.*, Brown's Essay).
5. He continued the subdivisions but reversed the names.
6. United them together, thus ending exactly where he commenced.

In 1766 the genus *Aulax* was founded by Bergius,† and in the following year ‡ he published descriptions of 17 species of Proteaceæ all of which he referred to the genus *Leucadendron,* but which consisted of species belonging to various genera. Less important are the works of Jacob Petiver, but as they contain a few figures of Proteaceæ may be mentioned. A considerable advance is marked by the writings of Carl Thunberg,§ the author described 60 species under the name of *Protea,* some of which are still recognised ; the text is accompanied by five plates of excellent woodcuts, and for the first time we find species of *Spatalla* and *Sorocephalus* figured. Much useful information as to habits and months of flowering is gleaned from Thunberg's account of the Order, and while his descriptions are not good as a means of determining a species, they are excellent, so far as they go, of the actual specimen which was described. Thunberg again published in 1794 || and dealt with 61 species of *Protea.* An account of the Order was written by

* R. Brown, *Trans. Linn. Soc.*, x. (1810).
† Bergius, "Vet. Acad. Hand. Stock.," 1766.
‡ Ibid., "Descriptiones plantarum ex Capite Bonæ Spei," 1767.
§ C. Thunberg, "Botanico de Protea," 1781.
|| Ibid., "Prodromus Plantarum Capensium," 1794.

Lamark,* and also by Willdenow,† but with the exception of a few novelties there is no advance on Thunberg, and both works are merely compilations of Thunberg's Dissertations on the Proteaceæ. In 1804 Poiret ‡ published; he goes a step further than Lamark, as a short general description follows each of the 74 species of *Protea* mentioned, but some of the species belong to Australian genera. Between the years 1797 and 1812 appeared various parts of Andrew's "Botanists' Repository," containing coloured plates of species which flowered in cultivation; a few species still recognised were first described in this work. After Thunberg's Dissertations the most important contribution to our subject was by R. A. Salisbury,§ and which marked the founding of several new genera. Salisbury again published in 1809 ‖ under the name of Knight, this publication being the first serious attempt to define and limit the genera in the Order. The material which Salisbury studied was, as pointed out above, mainly collected by Niven and cultivated in Hibbert's garden at Clapham. The collection must have been extensive, as we find 190 species described, which were grouped into 15 genera, viz., *Aulax*, Berg.; *Gissonia*, Salisb.; *Protea*, Linn.; *Euryspermum*, Salisb.; *Chasme*, Salisb.; *Serruria*, Burm.; *Erodendrum*, Salisb.; *Pleuranthe*, Salisb.; *Leucadendron*, Linn.; *Diastella*, Salisb.; *Mimetes*, Salisb.; *Paranomus*, Salisb.; *Soranthe*, Salisb.; *Spatalla*, Salisb.; *Brabeium*, Linn. The relation of these genera with those recognised by modern botanists will be dealt with when discussing Robert Brown's work. The "Proteeæ" has not received the recognition due to it, notwithstanding that it was the first serious scientific account of the Order published, and is useful, as it contains details as to localities and excellent notes on the habits of the various species made by Niven.

The classic work on the Proteaceæ was by Robert Brown,¶ who read a paper entitled, "On the Proteaceæ of Jussieu," before the Linnæan Society on January 17, 1809. Brown recognised 10 South African genera with 181 species, viz., *Aulax*, Berg.; *Leucadendron* (= *Protea*, *Euryspermum*, *Chasme*, *Gissonia* of Salisbury); *Leucospermum* (= *Leucadendrum*, Salisb.); *Serruria*, Salisb.; *Mimetes* (= *Mimetes* and *Diastella*, of Salisb.); *Nivenia* (= *Paranomus*, Salisb.); *Sorocephalus* (= *Soranthe*, Salisb.); *Spatalla*, Salisb.; *Brabeium*, Linn. The only differences we find in the limits of the genera of Brown and Salisbury are in *Protea*,

* Lamark, "Illustrationes."

† Willdenow, "Species Plantarum," 1797.

‡ Poiret, "Encyclopedie methodique," 1804.

§ R. A. Salisbury in the "Paradisus Londiensis," 1806, see pl. lxvii.

‖ Knight, "The Cultivation of the Plants belonging to the Natural Order Proteeæ," 1809.

¶ Trans. Linn. Soc., x. (1810).

Leucadendron, and *Mimetes*, the others are the same except in some cases for a change of name. For objections raised by Brown as to the names *Protea* and *Leucadendron* as used by Salisbury the reader is referred to Brown's original essay.

During the interval elapsing between 1810 and 1856 our knowledge of the Order was practically at a standstill. In 1813 Thunberg* published, enumerating 80 species of *Protea;* another edition† of the same work was published in 1818, but with no advance on the former. The first authors to take up Brown's genera were Romer and Schultes,‡ who described 167 species of Proteaceæ, but omitted the two diœcious genera, *Aulax* and *Leucadendron*. Although the descriptions are merely copies of Brown's and no new localities are given, yet we find here the first serious attempt to sweep together the existing synonyms. A third edition§ of Thunberg's "Flora Capensis," edited by Schultes, appeared in 1823, but notwithstanding it was published thirteen years after Brown, only the genus *Protea* with 84 species is mentioned. Two years later Sprengel‖ published and described 134 species of Proteaceæ (33 less than Romer and Schultes), but he included the genera *Aulax* and *Leucadendron* in the Linnæan class *Tetrandria monogynia*. These two genera, as pointed out above, were omitted by Romer and Schultes. This work is not of much importance, as the descriptions are merely compilations from Brown. In the following year Nees von Esenbeck¶ published a copy of Brown's essay, and three years later Link** gave descriptions of 2 species of *Leucadendron*, 3 species of *Protea*, and 1 species of *Serruria*. An account of the Order Proteaceæ with a list of genera by Bartling†† appeared in 1830, but is not of much importance. In 1835 Reichenbach‡‡ published four coloured plates of *Protea* with descriptions. This work is merely mentioned on account of the plates it contains. An important publication was that by Harvey§§ in 1838, who gave a good key to the genera based principally on the form of the inflorescence; two years previously the affinities of the Proteaceæ were discussed by Lindley.‖‖ A short account of the Order which may be noted was that by Ed. Spach¶¶

* Thunberg, "Flora Capensis," 1813. † Thunberg, "Flora Capensis," 1818.

‡ Romer and Schultes, "Syst. Veg." iii., 1818.

§ Thunberg, "Flora Capensis," ed. Schultes, 1823.

‖ Sprengel, "Syst. Veg.," 1825.

¶ Nees von Esenbeck "Robert Brown's Vermischte Botanische Schriften," ii., 55, 1826.

** D. H. F. Link, "Handbuch zur Erkennung, i., 382, 1829.

†† Fr. Th. Bartling, "Ordines Naturales Plantarum," pp. 115–118.

‡‡ Reichenbach, "Flora Exotica," 1835.

§§ Harvey, "Genera of South African Plants," ed. i., 1838.

‖‖ J. Lindley, "Natural System of Botany," pp. 197–200, 1836.

¶¶ Ed. Spach, "Histoire Naturelle des Vegetaux," vol. x., pp. 398–433, 1841.

in 1841. In 1843 Dr. Ernst Meyer edited Drège's "Zwei Pflanzengeographische, which while merely an enumeration of the plants collected by Drège, is of importance on account of the localities, altitudes, and months of flowering of the Proteaceæ which are scattered throughout the work. Almost simultaneous with this publication was a list of the Proteaceæ* collected by Zeyer and Ecklon, compiled by the former. Another list of those collected by Krauss appeared in 1844,† and was again reprinted in 1846.‡ A new genus, viz., *Faurea*, was described by Harvey in Hooker's "London Journal of Botany," representatives of which have since been found to occur in Madagascar. This fact is mentioned as Brown was struck by the absence of the Order from the island. The following year saw another new genus described, viz., *Orothamnus*, by Pappe, in the *Botanical Magazine*, t. 4357.

To bring all the scattered information on the Proteaceæ together was left to a German botanist, Dr. Meisner.§ Meisner followed Brown and adopted his genera, he included Harvey's new genus *Faurea*, but united Pappe's *Orothamnus* with *Mimetes*, R. Br., though keeping it in a separate section. He gave descriptions of 279 species, many of them new. It is due principally to the labours of Drège, Ecklon, Zeyher, Ludwig, and Krauss, who sent large quantities of material to Europe, that the South African members of the Order were so ably dealt with by Meisner, and his work remains up to the present the standard one. The second edition of Harvey's "Genera of South African Plants" appeared in 1868; the writer has taken Harvey's key as a model in preparing a key to the genera for the "Flora Capensis." The same year the Ray Society published "The Miscellaneous Botanical Works of Robert Brown,‖ among which will be found a reprint of Brown's monograph, which originally appeared in the Transactions of the Linnæan Society. In 1880 Bentham and Hooker published their "Genera Plantarum" with an excellent key and generic characters. This was followed in 1889 by an account of the Order by Engler.¶ An attempt was made by Otto Kuntze** to re-establish old generic names, but with regard to the South African Proteaceæ at least the scheme failed, and the names of the genera have now been decided upon by the Vienna Congress in 1905. The writer may mention, however, that if *Protea*, R. Br. is to be one of the *nomina conservanda* in preference to *Protea*, Linn., or *Protea*, Salisb., then *Leucadendron*, Berg., should be omitted, as *Protea*, R. Br., is as much *Protea*, Linn., as *Leuca-*

* "Linnea," xx., pp. 204–207.
† "Flora" (1844), pp. 74–77.
‡ Krauss, "Beitrage zur Flora des Cap-und Natallandes," 1846, pp. 138–141.
§ "D. C. Prodr.," xiv., 1856, pp. 209–482.
‖ Vol. ii., pp. 3–192.
¶ Engler in "Engler and Prantl Pflanzenfamilien," III., i.
** Otto Kuntze, "Revisio Generum Plantarum," 1891.

dendron, R. Br., is *Leucadendron*, Berg. In passing the various descriptions and plates which appeared at odd times in the *Botanical Magazine* and the *Botanical Register* may be noted.

The writer had been paying some attention to the South African Proteaceæ, and in 1910 undertook to monograph the Order for the "Flora Capensis." A vast amount of material had accumulated since Meisner's work appeared in 1856, a large percentage of which was new. Descriptions of new species have appeared in various numbers of the *Kew Bulletin*, and a description of a new genus will be found in the same publication. The genus *Diastella*, Salisb.,* has been taken out of *Mimetes*, R. Br., where it was placed by Meisner and given a generic status; *Orothamnus*, Pappe, will also be kept as a distinct genus. The separation of *Mimetes* as recognised by Meisner into the three genera *Mimetes*, R. Br., *Diastella*, Salisb., and *Orothamnus*, Pappe, and the establishing of the new genus *Spatallopsis*, Phillips,† brings up the number of the South African genera of Proteaceæ to 13.

In conclusion, and as a short summary of what has been said above, we find that there are four distinct stages in the advance of our knowledge of the South African Proteaceæ. The first was Boerhaave's publication in 1820, a serious beginning to the systematic work on the Order. Next followed Linnæus, who put systematic botany on a firm basis by the introduction of his binomial nomenclature. Salisbury and Brown mark a very distinct advance, as it was only then that the genera came to be recognised, and lastly it is due to Meisner, who enlarged on Brown and brought together all which had been published by previous authors, that our present knowledge of the Order is what it is to-day.

The writer takes this opportunity of thanking Dr. Otto Stapf, F.R.S., for kindly help which was given in looking up references in the older literature.

* The genus *Diastella*, *Journ. of Bot.*, vol. xliv., No. 577, p. 28.

† *Spatallopsis*, a new genus of Proteaceæ, *Kew Bull.*, 1910, No. 8.

TERRESTRIAL ISOMAGNETIC LINES FOR SOUTH AFRICA FOR THE EPOCH JULY 1, 1903.

By J. C. Beattie, D.Sc., F.R.S.S.Af.

(With Four Maps, Plates VIII., IX., X., XI.)

(Read June 21, 1911.)

The terrestrial isomagnetics dealt with in this paper are those of vertical, total, northerly, and westerly intensity. The true isomagnetics for these intensities for the epoch July 1, 1903, have already been given in another place ; * the data given there have been used in preparing the maps for the terrestrial lines, and in so far as they are here required are quoted in the following table :—

Table 1.

Mean Station of District.†	ϕ.	λ.	Z.	T.	X.	Y.
I.	33° 46′ S.	18° 57′ E.	·30669	·35681	·16034	·08727
II.	33 52	20 49	·31266	·36096	·15861	·08573
III.	33 36	23 0	·31845	·36530	·15771	·08347
IV.	33 25	25 1	·32298	·36848	·15775	·08132
V.	31 39	28 32	·32758	·37302	·16117	·07630
VI.	29 43	30 31	·32838	·37510	·16611	·07305
VII.	27 42	30 3	·32008	·37100	·17313	·07213
VIII.	27 57	27 49	·31570	·36736	·17258	·07515
IX.	25 59	30 14	·31572	·36999	·17946	·07065
X.	26 35	27 56	·31252	·36645	·17618	·07429
XI.	29 38	26 12	·31587	·36573	·16698	·07748
XII.	31 38	25 19	·31927	·36696	·16217	·08009
XIII.	31 58	21 31	·30962	·35973	·16255	·08409
XIV.	30 26	22 0	·30608	·35792	·16620	08310
XV.	23 53	29 44	·30722	·36615	·18671	·06947

The above results were next treated by the method first used by Mathias.‡ The mean station of District XI. was taken as reference

* "Report of a Magnetic Survey of South Africa," by J. C. Beattie, 1909, R.S.L.

† *Loc. cit.*, p. 52.

‡ "Annales de l'Observatoire Astronomique, Magnétique et Météorologique de Toulouse," T. 7. "Recherches sur le Magnétisme terrestre par E. Mathias." Paris, 1907.

point, and a table—No. 2—formed, in which are given the differences in longitude ($\Delta\lambda$), latitude ($\Delta\phi$), vertical intensity (ΔZ), total intensity (ΔT), northerly intensity (ΔX), and westerly intensity (ΔY).

TABLE 2.

Mean Station of District.	$\Delta\lambda$.	$\Delta\phi$.	ΔZ.	ΔT.	ΔX.	ΔY.
I.	−435′	+248′	− 918γ	−892γ	− 664γ	+979γ
II.	−323	+252	− 321	−577	− 837	+825
III.	−192	+238	+ 258	− 43	− 927	+599
IV.	− 71	+227	+ 711	+275	− 923	+384
V.	+140	+121	+1171	+729	− 581	−118
VI.	+259	+ 5	+1251	+937	− 87	−443
VII.	+231	−116	+ 421	+527	+ 615	−535
VIII.	+ 97	−101	− 17	+163	+ 560	−233
IX.	+242	−219	− 15	+426	+1248	−683
X.	+104	−183	− 335	+ 72	+ 920	−319
XII.	− 53	+120	+ 340	+123	− 481	+261
XIII.	−281	+140	− 625	−600	− 443	+661
XIV.	−252	+ 48	− 979	−781	− 78	+562
XV.	+212	−345	− 865	+ 42	+1973	−801

With these differences equations of the form—

$$\Delta(\text{mag. elem.}) = a + b\Delta\lambda + c\Delta\phi + d(\Delta\lambda)^2 + e\Delta\lambda\Delta\phi + f(\Delta\phi)^2$$

were obtained, and the values of the constants a, b, c, d, e, and f determined.

The results * for the four elements were as follows :—

$$\Delta Z_c = \cdot39009 + 4\cdot59073\Delta\lambda + 4\cdot86998\Delta\phi - \cdot00106(\Delta\lambda)^2 - \cdot0013172\Delta\lambda\Delta\phi - \cdot001934(\Delta\phi)^2$$

$$\Delta T_c = \cdot45302 + 3\cdot42021\Delta\lambda + 2\cdot13017\Delta\phi - \cdot0005825(\Delta\lambda)^2 - \cdot0010793\Delta\lambda\Delta\phi - \cdot0002655(\Delta\phi)^2$$

$$\Delta X_c = \cdot30017 - \cdot27939\Delta\lambda - 4\cdot84872\Delta\phi + \cdot0003224(\Delta\lambda)^2 - \cdot0020504\Delta\lambda\Delta\phi + \cdot0013477(\Delta\phi)^2$$

$$\Delta Y_c = \cdot66451 - 1\cdot90644\Delta\lambda + \cdot96844\Delta\phi - \cdot0005363(\Delta\lambda)^2 + \cdot0000609\Delta\lambda\Delta\phi - \cdot0007839(\Delta\phi)^2$$

From these equations the calculated values Z_c, T_c, X_c, Y_c, were found for the respective mean stations, and the differences between these and

* I have to thank Mr. Whittingdale of the Royal Observatory of the Cape of Good Hope for carrying out the necessary calculations.

the values given in Table 1 obtained. The results are shown in the following table:—

TABLE 3.

Mean Station of District.	$\Delta Z_c - \Delta Z$.	$\Delta T_c - \Delta T$.	$\Delta X_c - \Delta X$.	$\Delta Y_c - \Delta Y$.
I.	+ 2γ	−32γ	−22γ	+ 2γ
II.	−17	+64	+22	−10
III.	−27	−50	+39	− 4
IV.	+24	+11	−23	− 7
V.	+30	+20	−24	+14
VI.	−69	−35	+40	−16
VII.	+69	+55	+ 3	+ 8
VIII.	− 7	+ 2	−30	+ 2
IX.	+16	− 9	−31	+ 4
X.	−91	−55	+56	−23
XII.	+17	− 2	−23	+10
XIII.	− 9	−27	+ 4	+17
XIV.	+43	+41	− 7	− 7
XV.	+18	+15	− 4	+ 8

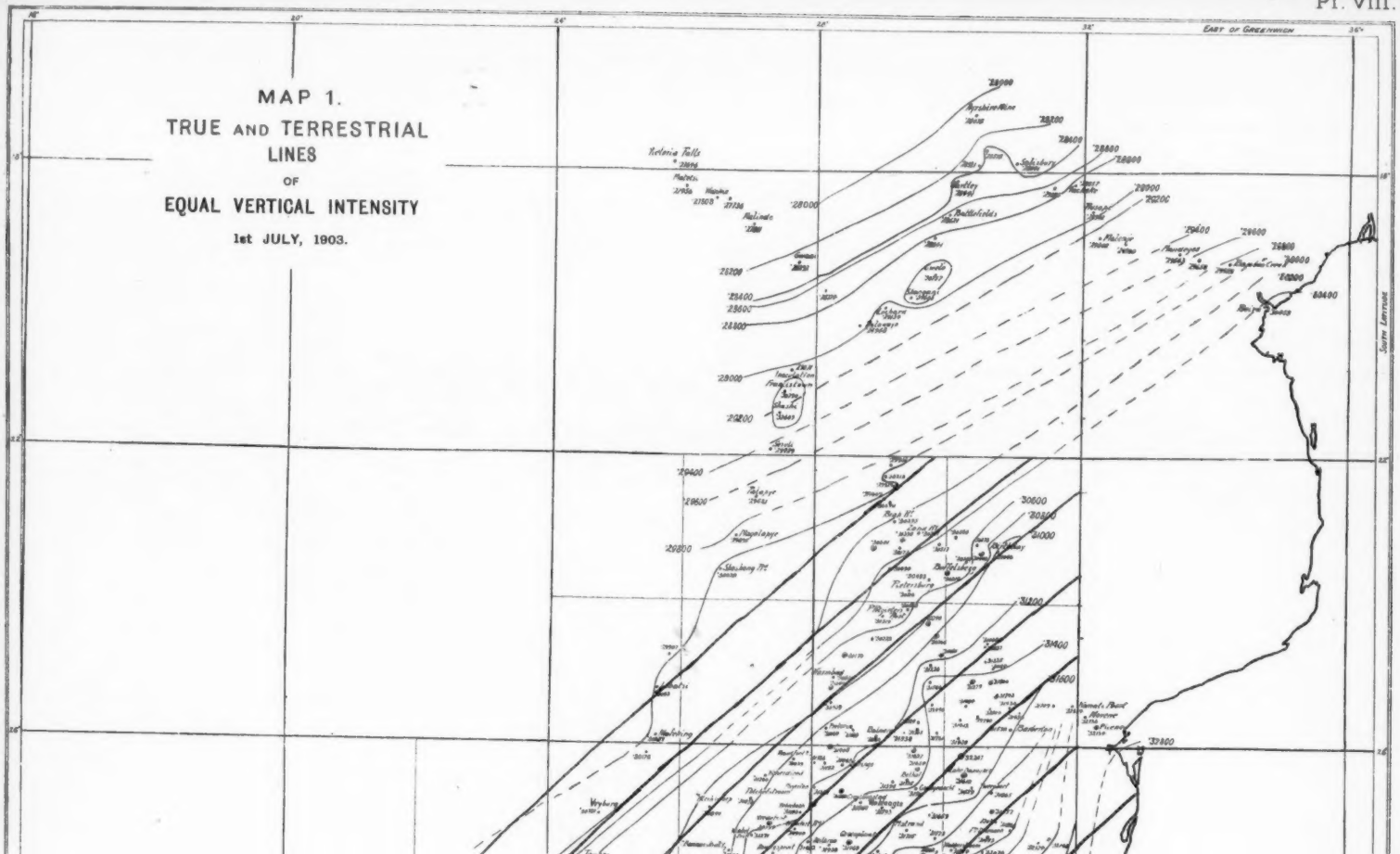
Finally, Table 4 gives the calculated values for the four intensities at the intersections of alternate whole degrees of latitude and of longitude. From these figures the respective terrestrial lines have been plotted as shown in maps 1, 2, 3, 4 (Plates VIII., IX., X., XI.).

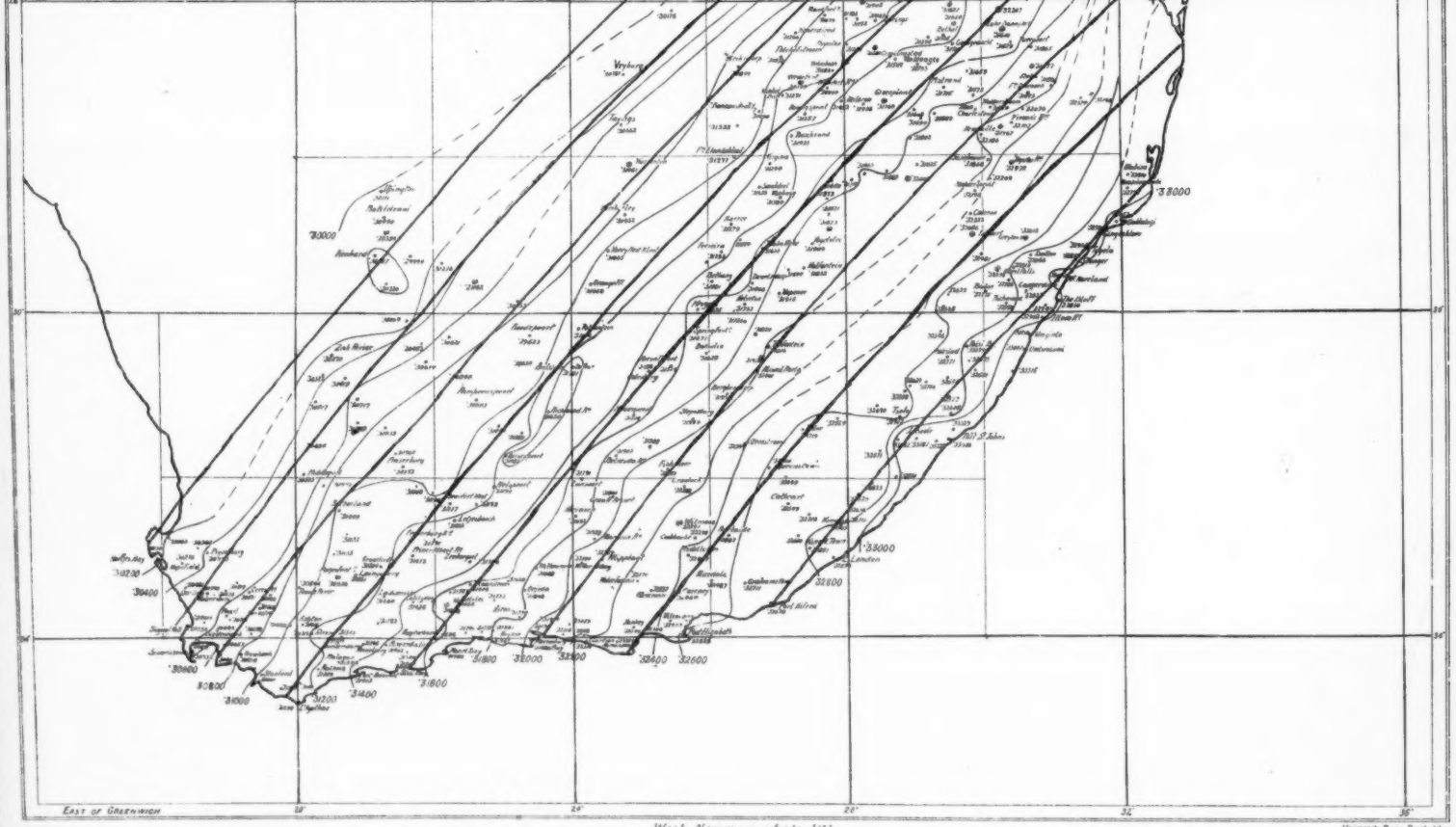
TABLE 4.

λ.	φ.	Z_c.	T_c.	X_c.	Y_c.
18°E.	34°S.	·30397	·35428	·16000	·08749
20	34	·31003	·35865	·15869	·08578
22	34	·31595	·36285	·15746	·08391
24	34	·32150	·36689	·15634	·08189
26	34	·32677	·37074	·15530	·07971
18	32	·29829	·35122	·16395	·08674
20	32	·30455	·35574	·16293	·08502
22	32	·31065	·36010	·16201	·08315
24	32	·31639	·36429	·16118	·08111
26	32	·32185	·36831	·16044	·07891
28	32	·32703	·37216	·15979	·07659
18	30	·29205	·34808	·16835	·08577
20	30	·29850	·35276	·16763	·08404
22	30	·30480	·35727	·16700	·08215
24	30	·31072	·36161	·16646	·08012
26	30	·31737	·36579	·16602	·07792
28	30	·32174	·36980	·16567	·07557
30	30	·32681	·37364	·16541	·07307
18	28	·28526	·34486	·17303	·08457
20	28	·29189	·34969	·17260	·08283
22	28	·29838	·35436	·17226	·08093
24	28	·30450	·35886	·17202	·07889

TABLE 4 (*continued*).

λ.	φ.	Z_C.	T_C.	X_C.	Y_C.
26° E.	28° S.	·31033	·36319	·17187	·07668
28	28	·31589	·36736	·17181	·07433
30	28	·32115	·37135	·17185	·07182
32	28	·32612	·37518	·17198	·06916
18	26	·27791	·34157	·17815	·08314
20	26	·28473	·34656	·17801	·08140
22	26	·29141	·35138	·17798	·07949
24	26	·29772	·35603	·17803	·07744
26	26	·30374	·36052	·17818	·07522
28	26	·30949	·36484	·17843	·07286
30	26	·31494	·36899	·17876	·07034
32	26	·32010	·37298	·17918	·06767
26	24	·29658	·35777	·18486	·07353
28	24	·30252	·36225	·18540	·07117
30	24	·30816	·36655	·18602	·06864
32	24	·31351	·37069	·18674	·06596
26	22	·28887	·35494	·19193	·07162
28	22	·29500	·35958	·19277	·06924
30	22	·30073	·36404	·19369	·06671
32	22	·30637	·36833	·19470	·06402

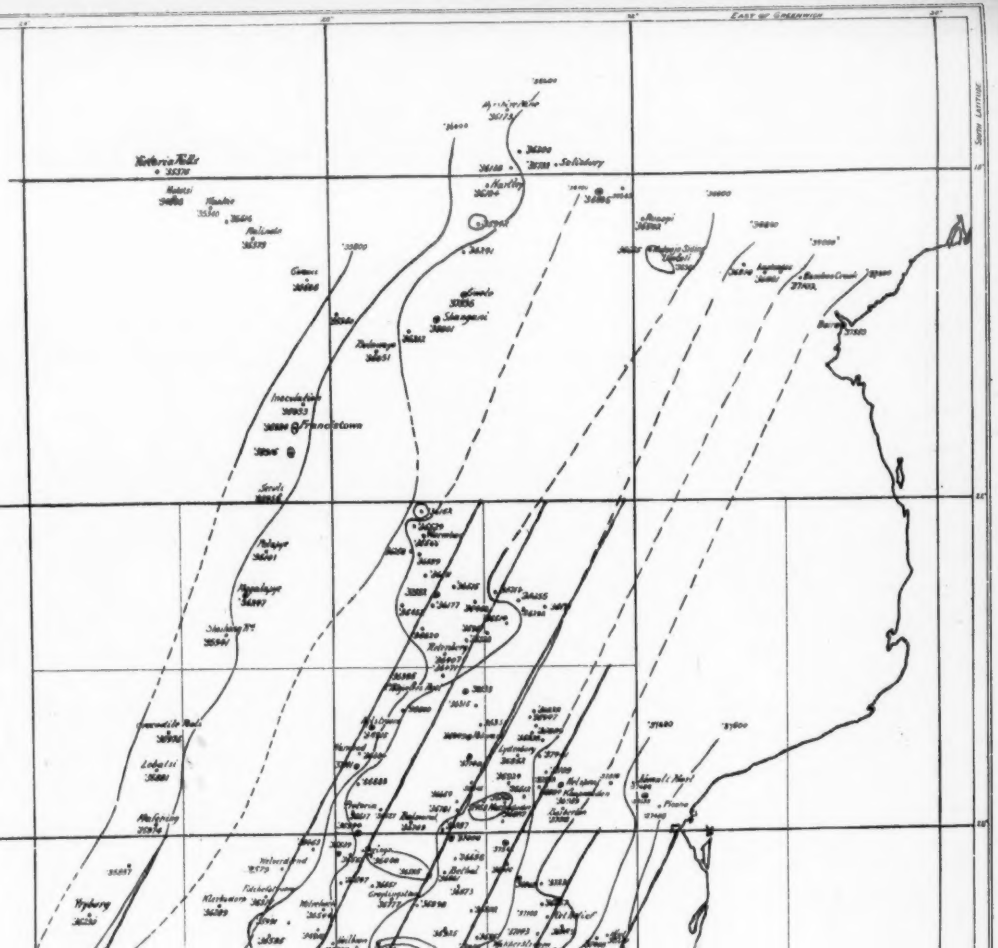

MAP 1.
TRUE AND TERRESTRIAL
LINES
OF
EQUAL VERTICAL INTENSITY
1st JULY, 1903.
EAST OF GREENWICH
South Latitude

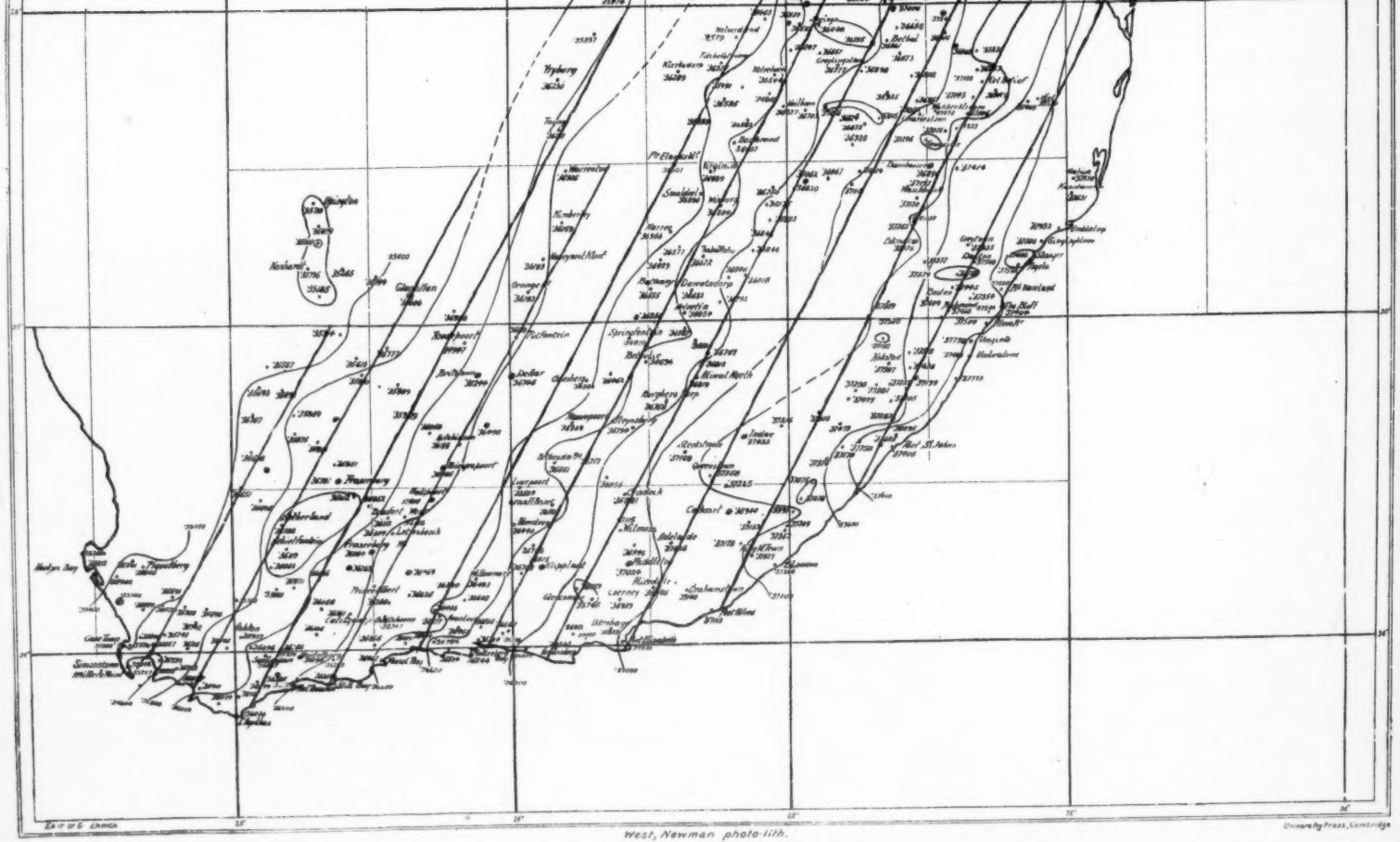

EAST OF GREENWICH
West, Newman photo-lith
University Press, Cambridge.

MAP 2.

TRUE AND TERRESTRIAL LINES OF EQUAL TOTAL INTENSITY

1st JULY, 1903.


EAST OF GREENWICH
SOUTH LATITUDE
Victoria Falls
Salisbury
Hartley
Umtali
Beira
Inscription
Francistown
Selukwe
Gwelo
Shangani
Belingwe
Bulawayo
Hope Fountain
Lobatsi
Mafeking
Wynberg
Kimberley
Johannesburg
Pretoria
Heidelberg
Klerksdorp
Potchefstroom
Krugersdorp
Barberton
Lydenburg
Standerton
Vryheid
Newcastle
Ladysmith
Harrismith
Pietermaritzburg
Durban
Kokstad
Umtata
Queenstown
Aliwal North
Bloemfontein
Kroonstad
Winburg
Ficksburg
Senekal
Harrismith
Vrede
Volksrust
Wakkerstroom
Piet Retief
Ermelo
Middelburg
Carolina
Barberton
Komatipoort
Pilgrim's Rest
Leydsdorp
Zoutpansberg
Pietersburg
Potgietersrust
Rustenburg
Zeerust
Mafeking
Vryburg
Kuruman
Taungs
Vryburg
Kimberley
Prieska
Hopetown
Colesberg
Cradock
Graaff Reinet
Somerset East
Port Elizabeth
Uitenhage
Grahamstown
East London
Kingwilliamstown
Queenstown
Cathcart
Stutterheim
Butterworth
Idutywa
Kentani
Umtata
Kokstad
Mount Ayliff
Mount Frere
Matatiele
Maseru
Thaba Nchu
Ficksburg
Harrismith
Bethlehem
Senekal
Winburg
Kroonstad
Heilbron
Frankfort
Vereeniging
Heidelberg
Nigel
Springs
Germiston
Boksburg
Benoni
Brakpan
Springs
Pretoria
Rustenburg
Potchefstroom
Klerksdorp
Wolmaransstad
Lichtenburg
Ventersdorp
Zeerust
Mafeking
Vryburg
Kuruman
Taungs



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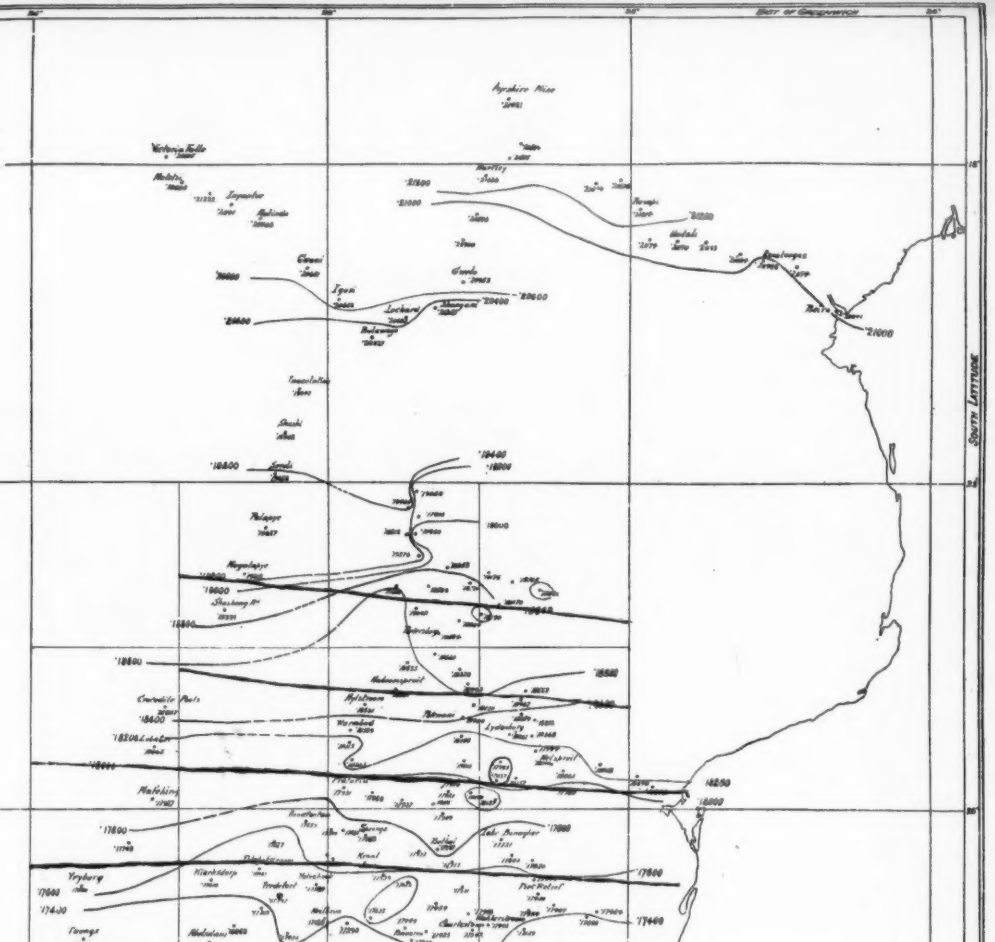
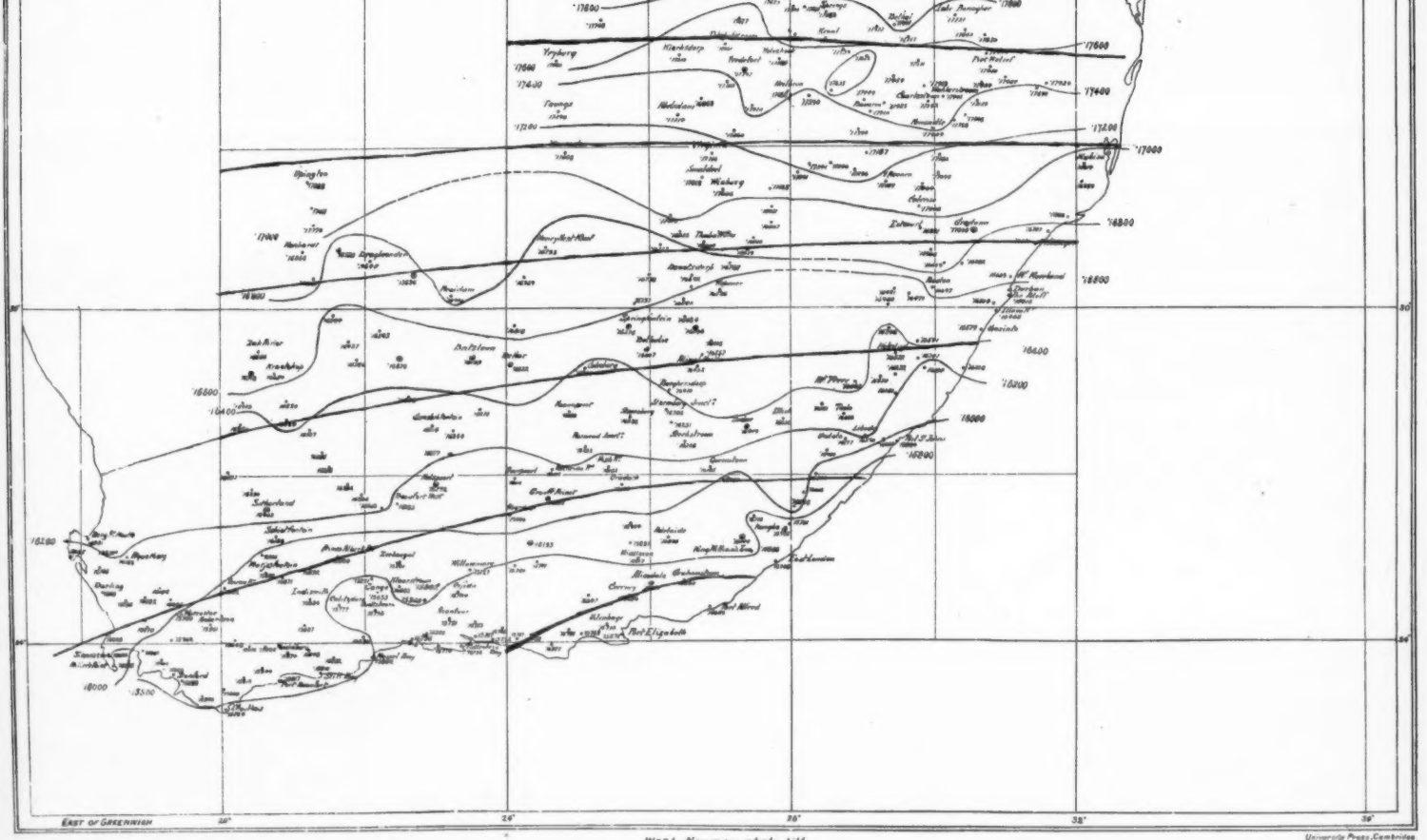
MAP 3.

TRUE AND TERRESTRIAL LINES OF EQUAL NORTHERLY INTENSITY

1st JULY, 1903.





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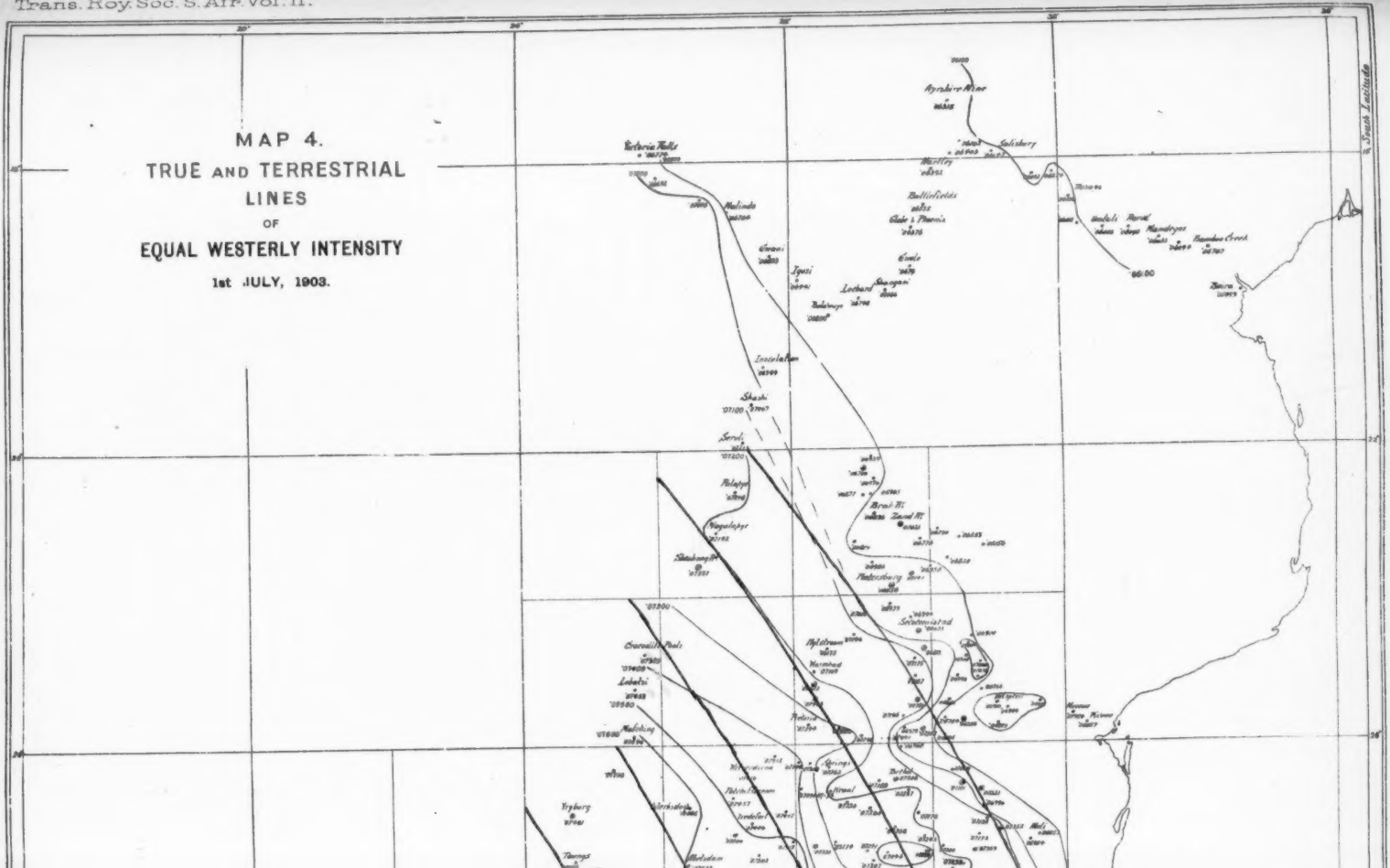
MAP 4.

TRUE AND TERRESTRIAL LINES OF EQUAL WESTERLY INTENSITY

1st JULY, 1903.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Livingstone
Ayrshire Mine
Salisbury
Umtali
Beaconsfield
Glade & Phoenix
Gwanda
Inyati
Lobengula
Shangani
Buluwayo
Inselaban
Shashi
Selukwe
Belingwe
Gwelo
Enkeldoorn
Mafeking
Vryburg
Taungs
Kimberley
Barkly West
Hopetown
Griquastad
Matatiele
Mount Ayliff
Umtata
Kokstad
Port St. Johns
Kei Mouth
East London
Grahamstown
Port Elizabeth
Uitenhage
Cradock
Graaff Reinet
Aberdeen
Willowmore
Oudtshoorn
George
Knysna
Mossel Bay
Riversdale
Swellendam
Caledon
Cape Town
Wellington
Worcester
Paarl
Stellenbosch
Malmesbury
Piquetberg
Clanwilliam
Calvinia
Van Rhyns Dorp
Springbok
Port Nolloth
Kuruman
Vryburg
Mafeking
Lobatsi
Gaberones
Crocodile Pools
Palapye
Shoshong
Francistown
Tati
Selukwe
Gwelo
Enkeldoorn
Umtali
Beira
Chimoio
Inhambane
Lourenco Marques
Delagoa Bay
Komatipoort
Barberton
Pilgrim's Rest
Lydenburg
Middelburg
Belfast
Machadodorp
Nelspruit
Standerton
Heidelberg
Vereeniging
Johannesburg
Pretoria
Rustenburg
Potchefstroom
Klerksdorp
Wolmaransstad
Bloemhof
Hartswater
Christiana
Taungs
Vryburg
Mafeking
Zeerust
Rustenburg
Pretoria
Johannesburg
Vereeniging
Heidelberg
Standerton
Ermelo
Piet Retief
Wakkerstroom
Newcastle
Dundee
Glencoe
Utrecht
Vryheid
Paulpietersburg
Eshowe
Stanger
Durban
Pietermaritzburg
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Ixopo
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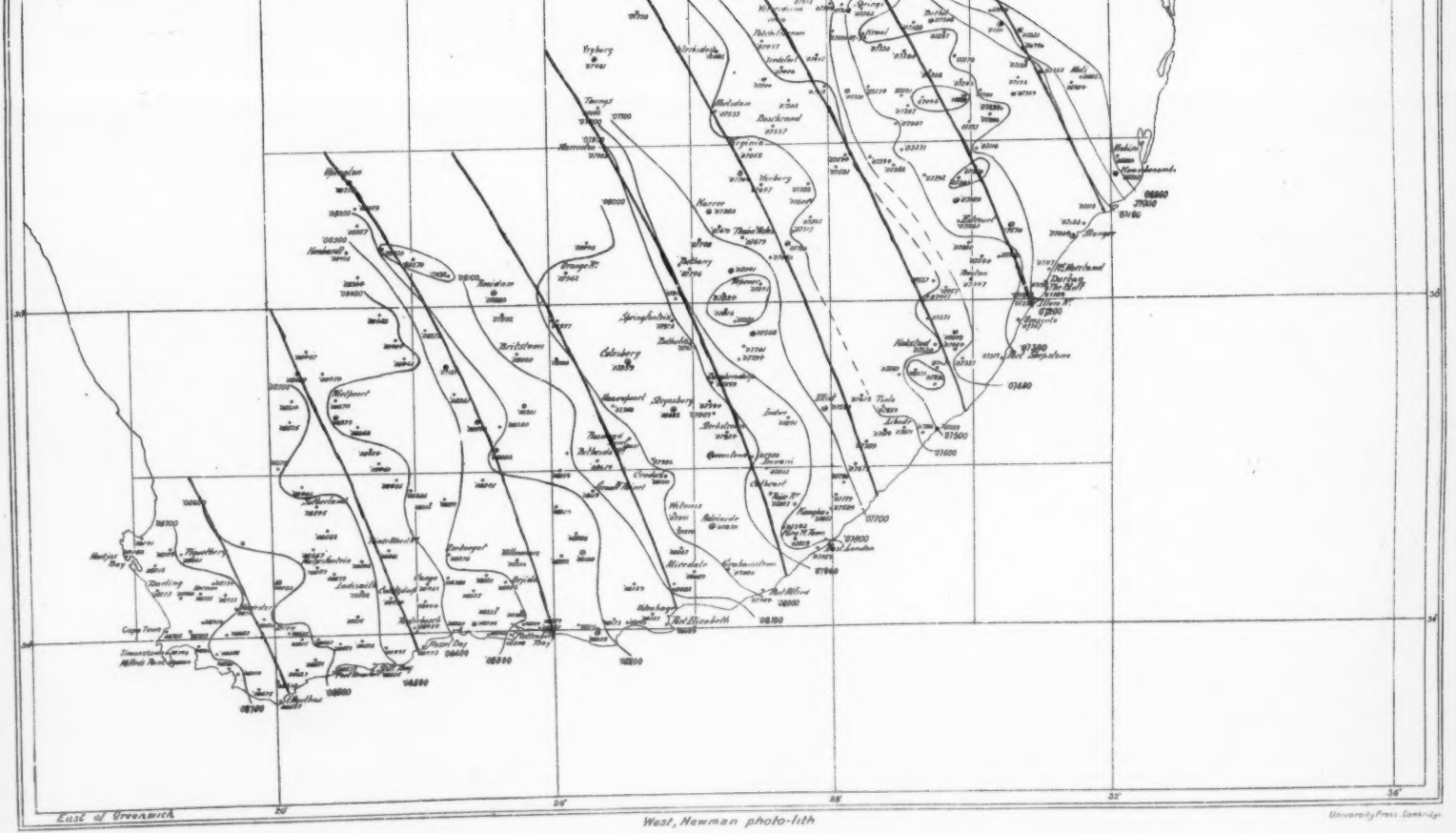
Umtata
Butterworth
Kei Mouth
East London
Queenstown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RELATIONS BETWEEN THE ECCENTRICITIES AND INCLINATIONS OF THE ORBITS OF THE PLANETS JUPITER AND SATURN.

By R. T. A. Innes, F.R.S.S.Af.

(Read June 21, 1911.)

It is well known that the eight major planets revolve around the Sun in nearly the same plane and in elliptical orbits which do not depart greatly from circularity.

In the cases of the Earth, Mars, Jupiter, and Saturn, the equators of these planets are not greatly inclined to the common plane of the orbits; the equators of Mercury, Venus, Uranus, and Neptune have not been seen, but from the motion of the satellites of Uranus and Neptune it is inferred that their equators have large inclinations.

The precise calculations of astronomers, which unfortunately can only extend to a few hundreds of years, agree with observation in showing that the eccentricities and inclinations of the various orbits are changing slowly. Lagrange, Laplace, and Poisson have proved that the mean-distances of the planets are essentially invariable, and the two former have, by very rough and inexact methods, shown that the sums of simple functions of the eccentricities and inclinations of all the planets will always remain small, but on account of the preponderating masses of the four outer planets the equations prove nothing as to the stability of the orbits of the four inner planets, of which group the Earth is one. It cannot to-day be proved that the orbit of such a planet as the Earth is stable. The large uniformity of flora and fauna for great ages gives rise to a no doubt well-founded belief that the Earth's orbit is stable, although there may be no mathematical proof yet available.

The case is different with the planets Jupiter and Saturn; the perturbations which these planets undergo, due to the presence of the other planets, are so insignificant compared to their own action on each other that they can be considered apart. In fact, the preponderating masses of the Sun, Jupiter, and Saturn in the solar system make these three bodies a nearly ideal case of the "problem of three bodies," and in consequence

of this the rigorous integrals given by Jacobi in his celebrated paper on the "Elimination of the Nodes" are closely approximated to.*

If we adopt the notation for Jupiter—

ι = inclination of orbit to the invariable plane,
e = eccentricity of orbit and $S\phi = e$,
m = mass,
a = ratio of Jupiter's mean distance to Saturn's,

and use accented symbols for the same quantities when applied to Saturn, and take the constant of attraction as unity, we have (see Charlier, "Mechanik des Himmels" formulæ of 14,* p. 274 of vol. i.)—

$$\begin{aligned} \beta\sqrt{a}C\phi S\iota - \beta_1 C\phi_1 S\iota_1 &= 0 \\ \beta\sqrt{a}C\phi C\iota + \beta_1 C\phi_1 C\iota_1 &= c_1, \end{aligned} \qquad (A)$$

in which—

$$\beta^2 = \frac{m^2}{1+m}, \qquad \beta_1^2 = \frac{m_1^2(1+m)}{1+m+m_1},$$

and C and S are written for cosine and sine, and c_1 is a constant. Taking—

$$1/m = 1047{\cdot}3, \qquad 1/m_1 = 3501{\cdot}6,$$
$$L\sqrt{a} = 9{\cdot}8682770{-}10,$$

and dividing the equation (A) by $\beta\sqrt{a}$, we get—

$$\begin{aligned} C\phi S\iota - qC\phi_1 S\iota_1 &= 0 \qquad & Lq &= 9{\cdot}6076936{-}10 \\ C\phi C\iota + qC\phi_1 C\iota_1 &= c \qquad & q &= 0{\cdot}4052225, \end{aligned}$$

in which both q and c are absolute constants.

Dr. G. W. Hill found by a comparison between the places given by his theory of Jupiter and Saturn and those actually observed that the reciprocals of the masses were 1047·38 and 3502·2 respectively; these values would change the value of Lq to 9·6076314–10, so that one must not lay too much stress on the value of this constant.

If we square and add the two equations, we get—

$$C^2\phi + 2qC\phi C\phi_1 C(\iota+\iota_1) + q^2 C^2\phi_1 = c^2.$$

* The not too great inequality of the three masses is also essential, and exists in the case of these three bodies—the integrals would furnish no useful information in the case of Jupiter, Sun, and Jupiter's 8th satellite, because of the smallness of the mass of JVIII, compared with Jupiter and the Sun.

We take the following figures from Hill's tables :—

$$\begin{aligned} \mathrm{L}e &= 8{\cdot}6835317-10 & \mathrm{LC}\phi &= 9{\cdot}9994938-10 \\ \mathrm{L}e_1 &= 8{\cdot}7486589-10 & \mathrm{LC}\phi_1 &= 9{\cdot}9993165-10 \\ \iota+\iota_1 &= 1^\circ\ 15'\ 20{\cdot}9'' & \mathrm{LC}(\iota+\iota_1) &= 9{\cdot}9998957-10 \end{aligned}$$

and thus have for the value of the constant c—

$$\begin{aligned} \mathrm{L}c &= 0{\cdot}1471664 & c &= 1{\cdot}4033512 \\ & & c^2 &= 1{\cdot}9693950 \end{aligned}$$

We can now make a rough discussion of the last equation, viz.—

$$\mathrm{C}^2\phi + 0{\cdot}81\,\mathrm{C}\phi\mathrm{C}\phi_1\mathrm{C}(\iota+\iota_1) + 0{\cdot}16\,\mathrm{C}^2\phi_1 = 1{\cdot}969.$$

As no cosine can exceed unity, and $\mathrm{C}\phi$, $\mathrm{C}\phi_1$, and $\mathrm{C}(\iota+\iota_1)$ are essentially positive, it is at once evident that at all times the C quantities must each be less than but yet exceedingly close to unity. If each is taken as unity the equation fails to balance, but only just fails, for we then have—

$$1 + 0{\cdot}810445 + 0{\cdot}164205 = 1{\cdot}974650,$$
whilst c^2 is actually $= 1{\cdot}969395$.

Thus the eccentricities and inclinations of the orbits of these two planets can never deviate greatly from their present small values.

Both ι and ι_1 can be determined in terms of e and e_1, and *vice versâ*. We have, in fact—

$$\mathrm{S}\iota/2 = \sqrt{\frac{(q\mathrm{C}\phi_1 + \mathrm{C}\phi - c)\,(q\mathrm{C}\phi_1 - \mathrm{C}\phi + c)}{4c\mathrm{C}\phi}}$$

$$\mathrm{S}\iota_1/2 = \sqrt{\frac{(q\mathrm{C}\phi_1 + \mathrm{C}\phi - c)\,(\mathrm{C}\phi - q\mathrm{C}\phi_1 + c)}{4cq\mathrm{C}\phi_1}}$$

$$\mathrm{C}\phi = c\frac{\mathrm{S}\iota_1}{\mathrm{S}(\iota+\iota_1)}$$

$$\mathrm{C}\phi_1 = \frac{c}{q}\frac{\mathrm{S}\iota}{\mathrm{S}(\iota+\iota_1)}$$

The first pair of these equations are ill-suited for finding the inclinations, because $q\mathrm{C}\phi_1 + \mathrm{C}\phi$ is very nearly equal to c. It is better to find ι and ι_1 by trial from the first equation of (A) ; we thus find—

$$\left.\begin{aligned} \iota &= 21'\ 16{\cdot}6'' \\ \iota_1 &= 54'\ 4{\cdot}3'' \end{aligned}\right\}\ 1850.$$

If we adopt the variations in e and e_1 and ι and ι_1 found by other investigators,* we can draw some further inference from the equation (A). Hill ("Collected Works," iv., p. 127) has discussed the maximum and minimum values of e and e_1, and he points out that the maximum eccentricity of one orbit corresponds with the minimum eccentricity of the other, and *vice versâ*. From Hill's figures we get—

$$\begin{aligned} &\mathrm{LC}\phi \text{ (min.)} = 9{\cdot}9991924\text{–}10 \qquad &&\mathrm{LC}\phi_1 \text{ (max.)} = 9{\cdot}9999705\text{–}10 \\ &\mathrm{LC}\phi \text{ (max.)} = 9{\cdot}9998597\text{–}10 \qquad &&\mathrm{LC}\phi_1 \text{ (min.)} = 9{\cdot}9984324\text{–}10 \end{aligned}$$

If we write the first equation of (A) thus—

$$\mathrm{S}\iota = q\frac{\mathrm{C}\phi_1}{\mathrm{C}\phi}\mathrm{S}\iota_1,$$

and substitute the above values of $\mathrm{C}\phi$ and $\mathrm{C}\phi_1$, we get—

$$\begin{aligned} \mathrm{S}\iota &= 0{\cdot}4044\ \mathrm{S}\iota_1. \quad \text{Min. of variable factor.} \\ &= 0{\cdot}4051\ \mathrm{S}\iota_1. \quad \text{Present value (1850).} \\ &= 0{\cdot}4054\ \mathrm{S}\iota_1. \quad \text{Max. value.} \end{aligned}$$

These equations show that ι and ι_1 increase or decrease together, and that with considerable precision we have at all times—

$$\Delta\iota = 0{\cdot}405\Delta\iota_1.$$

It must be remembered that $\Delta\iota$ and $\Delta\iota_1$ are the variations of the inclinations to the invariable plane of the system.

Stockwell ("Smithsonian Contributions to Knowledge," xviii., 1870) gives the following figures:—

$$\begin{aligned} &\text{Maximum value of } \iota+\iota_1 = 1^\circ\ 29'\ 35'' \\ &\text{Minimum value of } \iota+\iota_1 = 1\ \ 1\ \ 39 \end{aligned}$$

$$\begin{aligned} &\text{to which we add the present value} \quad = 1\ \ 15\ \ 20{\cdot}9\ (1850) \\ &\text{Value 2,000 years hence (Le Verrier)} \quad = 1\ \ 15\ \ 1\ \ (3850) \end{aligned}$$

These values show that with great accuracy we can write the second equation of (A) in the approximate form—

$$\mathrm{C}\phi + q\mathrm{C}\phi_1 = c \qquad \begin{cases} q = 0{\cdot}405 \\ c = 1{\cdot}403 \end{cases}$$

or making e and e_1 variable—

$$e\Delta e + qe_1\Delta e_1 = 0.$$

* The argument is complete without these, and logically they should not be used; but their use simplifies the reasoning.

This simple formula shows, as Hill has already pointed out from other considerations, that as e increases or diminishes e_1 decreases or increases, and that when e is at a maximum e_1 is at a minimum, and *vice versa*. It further shows that the variations of the eccentricities preserve the ratio $-0{\cdot}405 \times \frac{e_1}{e}$. Hill's Tables of Jupiter and Saturn do not give the variations of the eccentricities directly, but from them I have found the centennial variations to be—

Jupiter $+34{\cdot}06''$
Saturn $-71{\cdot}63$

These figures give a ratio of $-0{\cdot}409\frac{e_1}{e}$, which is a close accordance, especially when it is remembered that Hill's variations include the action of Uranus and the other planets.

It is remarkable that the ratio of the mean motion of Jupiter to that of Saturn ($=0{\cdot}4028$) is so close to the value of q ($=0{\cdot}4052$) and that the present ratio of the great inequality in the mean longitude of Saturn to the corresponding inequality of Jupiter (by Hill's tables $=0{\cdot}4113$) is again not widely different from q. These approximations may be fortuitous.

Summary.

The following relations, which are practically rigorous, connect the variations of the eccentricities and inclinations to the invariable plane of the planets Jupiter and Saturn :—

Jupiter.	Saturn.
$\Delta e = -0{\cdot}405\frac{e_1}{e}\Delta e_1$.	
$\Delta \iota = +0{\cdot}405\Delta \iota_1$.	

A NOTE ON THE LAND AND SEA BREEZES OF SOUTH AFRICA.

By J. R. Sutton, Sc.D., Hon. Memb. R.Met.S., F.R.S.S.Af.

(Read June 21, 1911.)

There is possibly room for some doubt whether the winds Mr. A. G. Howard has discussed in his paper, "An Investigation into the Land and Sea Breezes Conditions at Port Elizabeth,"* are, strictly speaking, land and sea breezes at all. A counter-clockwise rotation of the wind round the sub-solar point is common enough in our latitudes both at coast places and inland, as well as on islands. Thus, *e.g.*, at Kimberley there are prevailing winds approximately N.E. about sunrise, N.W. about noon, S.W. at sunset, and S.E. at midnight. An analysis of the winds of East London which I made some years ago showed a similar counter-clockwise rotation; but with northerly winds at midnight, and southerly winds at noon.† The difference in time-epoch for any direction between Kimberley and East London is no doubt attributable to a real land-and-sea-breeze effect. But the deduced mechanical resultant directions indicate that the sea breeze—such as it is—is at its height during the early hours of the afternoon, while the land breeze is in evidence from before midnight to sunrise. So far from either breeze existing at VIII. and XX., these are just the times when they have both practically died away.

Mr. Howard would have been upon more certain ground if he had got the loan of the continuous records of the anemometer belonging to Port

* *Trans. R. S. S. Af.*, vol. ii., pt. 2, 1911.

† "The Winds of East London," *Q. J. R. Met. S.*, April, 1905. See also the Presidential Address to Section A of the S. A. A. A. S., 1906.

Elizabeth Harbour Board, and worked up the directions for each hour. Probably if he had done so he would have found the same rule as prevails at various other coast places, *i.e.*, that the winds belong to three superimposed systems: (1) a more or less strong counter-clockwise diurnal rotation depending to some extent upon the season of the year; (2) prevailing winds (depending upon the pressure gradient) up or down the coast; and (3) a slight land-and-sea-breeze effect which at once perturbs the diurnal rotation and causes a deviation land- or sea-wards of the prevailing gradient winds. No study of South African winds promises to be quite complete unless it comprises at least four equidistant observations a day. When the observations are only made at two equidistant hours (*e.g.*, VIII. and XX.) they can only be of use as extending the continuous observations made at some adjacent observatory.

In this connection the winds of Delagoa Bay are of interest. The information given below is partly summarised and partly computed from the important second annual report of the Observatorio Campos Rodrigues.

The average velocities for the year 1910 are :—

TABLE 1.

MEAN HOURLY VELOCITIES OF THE WIND FOR EACH MONTH AT LOURENÇO MARQUES.

	Kilometers per Hour.	Miles per Hour.
January	20·94	13·0
February	21·05	13·2
March	22·03	13·8
April	20·67	13·1
May	21·01	13·0
June	21·92	13·6
July	20·91	13·0
August	23·94	14·9
September	26·83	16·6
October	25·91	16·1
November	27·19	16·9
December	25·94	16·1
Year	23·19	14·4

For the year, therefore, this gives a mean velocity only 72 per cent. of that of the wind of East London.

TABLE 2.

MEAN HOURLY VELOCITIES OF THE WIND FOR EACH HOUR AT LOURENÇO MARQUES.

Hour.	Kilometers.	Miles.
I.	19·8	12·2
II.	19·7	12·2
III.	20·2	12·6
IV.	20·8	13·0
V.	20·5	12·7
VI.	20·4	12·7
VII.	21·0	13·1
VIII.	21·2	13·2
IX.	22·2	13·8
X.	22·5	14·0
XI.	21·9	13·6
Noon	22·5	14·0
XIII.	23·8	14·8
XIV.	24·4	15·2
XV.	26·8	16·6
XVI.	27·7	17·2
XVII.	28·4	17·6
XVIII.	28·1	17·4
XIX.	27·4	17·0
XX.	25·9	16·1
XXI.	25·0	15·6
XXII.	22·9	14·2
XXIII.	21·3	13·2
Midnight	20·3	12·6

This differs considerably from the diurnal curves of velocity for Kimberley and East London in that while these two last show the greatest velocity for the day between XIII. and XIV. o'clock, at Lourenço Marques the maximum velocity comes in the late afternoon. A curious feature—not altogether unknown elsewhere, however—in the diurnal curve for the latter place is the fall in velocity in most of the months at 11 a.m.

Table 3 shows the prevailing winds during each quarter of the year. It shows the number of hours in each quarter in which the vane was pointing in any given direction.

TABLE 3.

WIND FREQUENCY IN HOURS FOR EACH QUARTER OF THE YEAR.

	Jan. to March.	April to June.	July to Sept.	Oct. to Dec.	Year.
N.	35	141	212	95	483
N.N.E.	47	104	114	97	362
N.E. ...	42	89	185	269	585
E.N.E.	278	190	199	228	895
E.	233	93	110	165	601
E.S.E.	258	117	90	187	652
S.E. ...	106	54	63	128	351
S.S.E....	242	124	105	183	654
S.	41	45	107	244	437
S.S.W.	414	266	198	229	1,107
S.W. ...	201	270	228	53	752
W.S.W.	67	122	80	18	287
W.	9	43	41	37	130
W.N.W.	71	102	87	61	321
N.W. ...	44	84	138	82	348
N.N.W.	72	340	251	128	791

The numbers of Table 3 give the following North and East Components of direction, Kimberley values for 1910 being added for comparison :—

TABLE 4.

WIND DIRECTION COMPONENTS.

	Lourenço Marques.		Kimberley.	
1910.	N.	E.	N.	E.
January to March	−643	+448	+321	+394
April to June	+ 59	−167	+209	+416
July to September	+234	+ 10	− 44	+429
October to December	−169	+594	− 27	+191
Year	+519	+885	+459	+1,430

Table 4 shows that wind directions in Delagoa Bay prevail in the south-east quadrant (*i.e.*, from the sea) from October to March, being rather to the north of east-south-east from October to December, and slightly to the north of south-south-east from January to March; whereas in the winter half of the year there is a small preponderance of direction from the land, say, from a west-north-west direction during April–June, and from nearly due north from July to September. (See Fig. 1.)

Considering the total duration for the year of each wind direction we find that the commonest winds are south-south-west, east-north-east, and north-north-west, in order of frequency. That is to say, the prevailing

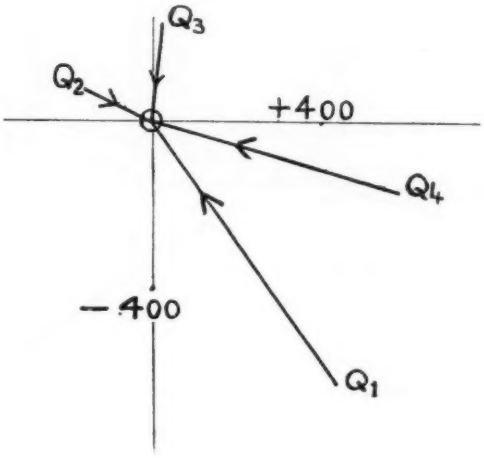


Fig. 1.

winds blow up or down the coast as they do at East London. The winds of secondary importance, namely, those from the north-north-west, are mainly a winter phenomenon. They occur also at East London at the same season, albeit the duration there is relatively less important than it is in Delagoa Bay. At both places they may fairly be regarded as arising from similar barometric conditions, and as blowing from the cooled interior to the warmer area dominated by the Mozambique Current. Besides being winter winds they are also essentially night and morning winds, for they appear but rarely in the afternoons. It is these winds that are usually responsible for the hot (foehn) winds of the coast belt during the late winter and early spring months.

So far as one year's observations can be trusted, then, the results of the wind observations at Lourenço Marques show—as the longer period at East London showed—that the current statements, and the physical atlases, are wrong in the prevailing directions they assign to the winds of the south and south-east coast of South Africa. The "prevailing south-east rain-bearing wind" is, in fact, a myth; and as Captain Campbell Hepworth has pointed out (though little notice seems to have been taken of his testimony), south-east winds may blow fifty or a hundred miles to seaward, yet they are deflected as they approach the coast, so as to take the direction of the coast-line.*

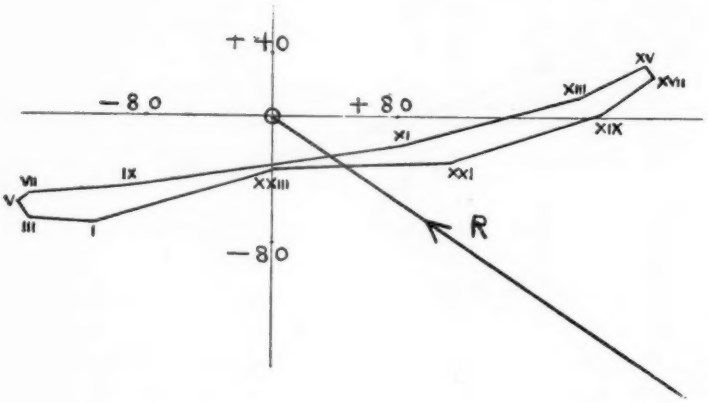


FIG. 2.

Of more immediate consequence to the main subject-matter of this paper, however, is the diurnal oscillation of the vane at Lourenço Marques. In the Report from which the greater part of the above information has been extracted the directions and velocities have been given for every alternate hour of each day, *i.e.*, at I., III., V., VII., &c. I have tabulated the directions for each given hour and worked out their Cartesian components. The component velocities have not been dealt with here, the business being simply with the directions at particular hours. Results are given in Table 5.

* M. W. Campbell Hepworth, "Weather Forecasts and Storm Warnings on the Coast of South Africa." Read before the Meteorological Society in February, 1883. Reprinted in "Notes on Maritime Meteorology," 1907.

TABLE 5.

DIURNAL VARIATION OF WIND FREQUENCY IN HOURS.

	I.	III.	V.	VII.	IX.	XI.	XIII.	XV.	XVII.	XIX.	XXI.	XXIII.
N.	23	22	25	28	18	22	19	15	15	14	15	29
N.N.E.	14	6	4	7	2	5	5	3	19	36	47	33
N.E.	4	7	4	—	2	9	27	52	66	51	49	25
E.N.E.	10	4	4	4	8	20	66	103	88	72	39	23
E.	9	3	3	4	8	43	71	50	37	29	22	18
E.S.E.	5	3	3	4	10	53	54	49	48	44	26	9
S.E.	5	3	2	3	17	31	26	22	33	24	20	8
S.S.E.	20	11	7	11	23	33	23	26	31	54	56	28
S.	25	24	24	18	36	12	8	5	8	14	26	30
S.S.W.	74	79	80	80	57	31	12	14	8	13	36	59
S.W.	55	66	64	62	45	17	9	4	4	4	12	41
W.S.W.	23	27	32	31	15	6	3	1	2	3	1	8
W.	18	14	11	8	6	1	1	—	—	1	2	4
W.N.W.	20	29	30	31	14	8	2	1	1	—	6	16
N.W.	21	23	24	22	39	16	8	3	3	3	4	11
N.N.W.	39	44	48	51	65	58	31	17	2	3	4	23

These numbers give the Cartesian components of Table 6, which are also shown graphically in Fig. 2.

TABLE 6.

WIND DIRECTION COMPONENTS.

Hour.	N.	E.
I.	−64	−112
III.	−65	−153
V.	−59	−162
VII.	−51	−154
IX.	−46	− 91
XI.	−19	+ 82
XIII.	+16	+196
XV.	+33	+235
XVII.	+28	+240
XIX.	+ 2	+209
XXI.	−27	+135
XXIII.	−30	− 0
Day	−283	+425

The mean resultant direction for the day is from somewhere to the north of south-east, due, no doubt, to the influence of the trade winds; * while the hourly resultants show land- and sea-breeze movements approximately parallel to the north arm of the oblique angle of coast forming Delagoa Bay. The sea-breeze effect as depicted in Fig. 2 is at its height from XV. to XVII. o'clock, while the land breeze reaches its maximum just before sunrise. The counter-clockwise rotation of the vane is not apparent at Lourenço Marques.

* The mean resultant direction at East London is almost exactly from the opposite direction.

EXPLANATION OF THE FIGURES.

In Fig. 1, the vectors Q_1O, Q_2O, Q_3O, Q_4O represent the resultant directions in magnitude and direction for each quarter of the year.

In Fig. 2, the resultant direction for any hour is supposed to blow from the place of that hour on the diagram to the origin O. Thus, *e.g.*, at XIX. o'clock the resultant direction is from almost due east. The vector RO represents the total resultant direction for the year in direction, but on a reduced scale.

THE ALGEBRAICAL DEVELOPMENT OF THE ELLIPTIC PERTURBATIVE FUNCTION USED IN THE THEORIES OF PLANETARY MOTION.

By R. T. A. Innes, F.R.S.S.Af.

(Read October 18, 1911.)

The methods of computing the motions of the planets devised by Lagrange and Laplace and used by the great planetary investigators of last century such as Le Verrier, Hansen, and Newcomb, require an expansion of the reciprocal of the distance between two planets. The most general expansion is an algebraical one, which, if it is to be useful in practical work, requires that the eccentricities and mutual inclinations of adjacent planetary orbits should be small—these conditions are fulfilled for all the major planets and for the majority of the minor planets of the solar system. Hence, great attention has been devoted in the past to this algebraical expansion. The most useful, but at the same time the most complicated development, is in terms of the mean anomalies of the planets concerned, and it is this development which is dealt with here. References may be made to the following works :—

Le Verrier, *Les Annales de l'Obs. de Paris*, vols. i. and x.
Tisserand, *Mécanique Celeste*, vols. i. and iv.
Hill, *Collected Works*, vol. ii
Newcomb, *American Journal of Mathematics*, vol. iii., and *Astronomical Papers of the American Ephemeris*, vol. v.
Cowell, *Monthly Notices of the Royal Astronomical Society*, vol. lxix.

The object of the present paper is purely practical ; it is to put in the hands of the computer a development which extends to any order for primary or secondary terms, and is substantially ready for use. A

numerical application to the theory of the planets Jupiter and Saturn has been commenced, but its completion is still far off.

The most extended tables of the algebraical development of the perturbative function in terms of the mean anomalies, are due to Le Verrier (*Les Annales*, i. and x.), but a more methodical and general development has been given by Newcomb (*Astronomical Papers of the American Ephemeris*, v.).

Le Verrier's development has been extended by Boquet to terms of the 8th order of both the eccentricities and mutual inclination, and this limit has also been adopted by Newcomb. The remarks which follow will apply more especially to Newcomb's development, but with suitable changes they can, if necessary, be adapted to Le Verrier's; it is not, however, likely that any one who is familiar with both developments will prefer Le Verrier's—the use of the operator $D = a\frac{d}{da}$ by Newcomb is alone sufficient to turn the scale.

Every term of the development has the form*—

$$e^n e_1^{n'} \overset{k}{P}{}^{n,n'}_{j,j'} \cos (\overset{k}{V}_i + jg + j'g')$$

in which k indicates the presence of the factor σ^{2k} (σ = sine of semi-inclination). The order of this term will be equal to $n+n'+2k$.

This paper will deal with the properties of the quantities $\overset{k}{P}{}^{n,n'}_{i,j'}$, the expressions for which form the only difficulty in the development. As it is very easy to pass from $\overset{0}{P}$ (henceforth written P) to $\overset{1}{P}$, $\overset{2}{P}$, $\overset{3}{P}$, &c., attention will be confined to the former.

In any given term we find a series of this form—

$$e^i e_1^{j'} (P^{j,j'}_{j,j'} + e^2 P^{j+2,j'}_{j,j'} + e_1^2 P^{j,j'+2}_{j,j'} + e^2 e_1^2 P^{j+2,j'+2}_{j,j'} + \text{ &c.})$$

(In which the suffices only may be negative and then only under certain conditions.)

The first quantity $P^{j,j'}_{j,j'}$ will be called the primary term, those multiplied by e^2 or e_1^2, the secondary terms, those by $e^2 e_1^2$, e^4 or e_1^4 tertiary terms and so on. Terms in which the suffices j or j' are negative are secondary or higher order terms, although they are closely related to the primary terms.

* It is assumed that the reader is conversant with the notation used by Newcomb in the papers above referred to.

But before going on, a further important simplification can be introduced. With Newcomb, we write—

$$P^{n.n'}_{j.j'} = \Pi^{n.n'}_{j.j'} a_1 A_i,$$

(*Ast. Papers*, v., p. 27, &c.)

in which the operator—

$$\Pi^{n.n'}_{j.j'} = \Pi^{n.o}_{j.o} \times \Pi^{o.n'}_{o.j'}.$$

Further, as also discovered by Newcomb, the operator $\Pi^{o.n'}_{o.j'}$ can be found from $\Pi^{n.}_{j.}$ very simply. Hence the real crux is to find expressions for Π^{n}_{j}. The primary operator in any term will be Π^{n}_{n}, the secondary Π^{n+2}_{n}, the tertiary Π^{n+4}_{n}, &c., &c. The expresssions to Π^{s}_{j} in terms of i and D are given by Newcomb. The operators with negative suffices are, as already mentioned, at least secondary.

On account of its complexity, it is almost impossible to give a general and useful formula for Π^{n}_{j} in terms of the D operators. Such a formula starts thus—

$$\begin{aligned}(-1)^{j} f(n.j)\Pi^{n} = {} & + && D^{n} \\ & + \left(2ji - \frac{n(n-3)}{2} + j^{2}\right) && D^{n-1} \\ & + \Big\{ -2i^{2}(n-j^{2}) \\ & \quad - \frac{ji}{2}(7 - 13n + 2n^{2} + 4j^{2}) \\ & \quad + \frac{n}{24}(3n^{3} - 22n^{2} + 45n - 26) \\ & \quad + j^{2}(n^{2} - 6n + 4) && + j^{4} \Big\} D^{n-2} \\ & \quad \text{&c., &c.}\end{aligned}$$

In which—

$$f(n.j.) = 2^{n} n! \frac{1 \quad 2 \quad 3 \quad \ldots \quad \frac{n-j}{2}}{n.n-1.n-2 \ldots \frac{n+j+2}{2}} \quad \text{and} \quad f(n.0) = 2^{n} n!$$

The extent given will merely serve to $n=2$, although it will always serve as a check on the coefficients of the three highest D operators in any value of Π^{n}_{j}.

The primary terms are the more important as the succeeding terms are factored by powers of e^{2}, &c. In the "Variation of Elements" method of computing perturbations, the secondary terms become the leading terms in several of the coefficients, but in the final expressions for the perturbations of the longitude or mean anomaly the primary terms reassert their predominance. Thus in the theory of the motion of the earth we find the following perturbations of the longitude :—

Argument.	Action of—	Primary.	Secondary.	Tertiary.
		"	"	
$l' - \lambda$	Mercury	+0·130	−0·003	Nil
$l' - \lambda$	Venus	+3·813	−0·002	Nil
$13l' - 8\lambda$	Venus	−1·253	−0·003	Nil
$13l' - 8\lambda$	Venus	+2·091	−0·012	Nil
$l' - \lambda$	Mars	+0·102	+0·006	Nil
$15l' - 8\lambda$	Mars	+0·161	−0·009	Nil
$2l' - 2\lambda$	Jupiter	+1·901	−0·012	Nil

(See for further examples Le Verrier's "Theory of the Sun" (*Les Annales*, iv., pp. (9)–(18)). The secondary terms given appear to be the largest in this theory.)

In the action of Saturn on Jupiter we find—

Argument.	Primary.	Secondary.	Tertiary.
	"	"	"
$3l' - 2\lambda - \omega'$	+26·79	− 0·10	+0·02
Largest individual term of the Great Inequality	−1522·78	+11·18	+0·41

(See *Les Annales*, xi., p. 121, &c.)

In the last case the next term may be estimated at about 0″·04. For such a quantity to have any real significance we must know the mass of Saturn correctly within its $\frac{4}{3000000}$ part, and the annual motion of Jupiter within 0″·00008. Both of these requirements are beyond our power of attainment; in short, terms of the tertiary order are of very little importance, whilst those of the next order are quite negligible in the theories to which an algebraical development can be applied.

It may, however, be necessary to include such terms in the consideration of the secular perturbations, but in this case it is possible to give general expressions of great simplicity, extending to any powers of the eccentricities and mutual inclinations, and these will be found in the last table of the present paper.

Chessin has shown (*Ast. Journal*, No. 442, 1898) that it is possible to simplify the expressions for the computation of the values of the Newcomb operators; he gives the following example :—

Newcomb—

$$\begin{aligned}7680\Pi_4^6 = {} & D^6 + (8i - 25)D^5 + (20i^2 - 130i + 185)D^4 + (-80i^2 + 340i - 255)D^3 \\ & + (-80i^4 + 640i^3 - 1765i^2 + 2280i - 1466)D^2 \\ & + (-128i^5 + 1360i^4 - 5280i^3 + 9535i^2 - 8454i + 3096)D \\ & + (-64i^6 + 800i^5 - 3740i^4 + 8200i^3 - 8588i^2 + 3608i).\end{aligned}$$

Chessin—

$$\Pi_7^6 = 6\Pi_6^6 + 2(i-5)\Pi_5^5 - (\tfrac{3}{4}i-2)\Pi_4^4 - (i-\tfrac{1}{4})\Pi_3^3 - \tfrac{1}{192}(2i-1)\Pi_2^2 - \tfrac{9}{3840}(5i-1)\Pi_1^1 - \tfrac{3}{1536}i$$

Chessin's formula has two advantages; firstly, it is much shorter; secondly, it throws the computation of the secondary terms on to those of the first. In ordinary course the primary terms must be computed first, and it is fitting that they should form the basis for the secondary and higher terms. But neither Newcomb nor Chessin gave a general expression for the operators, and, in point of fact, it requires a very lengthy calculation to check, far less to extend, Newcomb's tables.

Let us suppose that we are dealing with the primary operator Π_8^8; Newcomb's formula starts thus—

$$10321920\Pi_8^8 = 256i^8 - 8960i^7 + 130592i^6 - 1023120i^5 + 462807i^4 + \&c.$$
$$\text{plus terms in D, D}^2\text{... to D}^8.$$

The figures bear no obvious relation to each other, and have to be taken on trust; besides this, the computation for a particular value of i is exceedingly arduous. The length of the expression for Π_9^9, Π_{10}^{10}, &c., is appalling; it is true that the use of the Chessin formulæ would shorten the calculation, but Chessin does not give the constants his method requires for operators beyond Π_6^6 and Π_5^5. Chessin's constants for Π_n^n are, however, not difficult to find, as they are connected with certain Besselian series for e used in Hansen's planetary theory.

Newcomb gives, on p. 13 of vol. v. of the *Astronom. Papers of the American Ephemeris*, the general recurrent formula by which he builds up Π_n^n; it is—

$$\begin{aligned} 2(n+1)\Pi_{n+1}^{n+1} &= (k_1'\mu + h_1'\mathrm{D})\Pi_n^n \\ &+ (k_2''\mu + h_2''\mathrm{D})\Pi_{n-1}^{n-1} \\ &+ \ldots\ldots\ldots\ldots \\ &+ (k_{n+1}^{n+1}\mu + h_{n+1}^{n+1}\mathrm{D})\Pi_0^0 \end{aligned}$$

in which the factors k and h depend upon the developments of the equation of the centre and the logarithm of the radius vector in terms of the mean anomaly. The succession of the values of the k's given by Newcomb (p. 22 *loc. cit.*) are—

$$2,\ \frac{5}{2},\ \frac{13}{4},\ \frac{103}{24},\ \frac{1097}{192},\ \frac{1223}{160},\ \frac{47273}{4608},\ \frac{556403}{40320}$$

What the next fraction will be is by no means clear, but it will be seen immediately that the values are really not wanted, as a transformation at once discloses the values of the successive terms. Let us write out the Newcomb values for Π_1^1, Π_2^2 in the following form :—

Π^0_0.	$2\Pi^1_1$.	$8\Pi^2_2$.	$48\Pi^3_3$.	
$-(2i+\mathrm{D})$	-1			(a)
$-(5i+3\mathrm{D})$	$-(2i+\mathrm{D})$	-1		(b)
$-(26+17\mathrm{D})$	$-(10i+6\mathrm{D})$	$-(2i+\mathrm{D})$	-1	(c)
&c.	&c.			

which is read as follows:—

$$0 = -(2i+\mathrm{D})\,\Pi^0_0 - 2\Pi^1_1 \text{ \&c.}$$

Subtract now $3(a)$ from (b), and generally subtract whole multiples of (a) (b)... from the following letter and the following table results:—

Π^0_0.	$2\Pi^1_1$.	$8\Pi^2_2$.	$48\Pi^3_3$.	
$-(2i+\mathrm{D})$	-1			$(a)'$
i	$-2i+3-\mathrm{D}$	-1		$(b)'$
$2i$	$2i-1$	$-2i+6-\mathrm{D}$	-1	$(c)'$
&c.	&c.			

The final results are presented in Table I.A, which contains precepts for its indefinite extension. The $\Pi^{0,n'}_{0,n'}$ will be found in Table I.B. It will also be seen that the property—

$$\Pi^{n,n'}_{j,j'} = \Pi^n_j \times \Pi^{0,n'}_{0,j'}$$

falls naturally into the scheme of these tables.

In practice we first compute—

$$2\Pi^1_1,\ 8\Pi^2_2,\ 48\Pi^3_3 \ldots \text{ \&c.}$$

and—

$$2\Pi^{0,1}_{0,1},\ 8\Pi^{0,2}_{0,2},\ 48\Pi^{0,3}_{0,3} \ldots \text{ \&c.}$$

then—

$$4\Pi^{1,1}_{1,1},\ 16\Pi^{2,1}_{2,1},\ 96\Pi^{3,1}_{3,1} \ldots \text{ \&c.}$$

and so on, step by step, each individual step being simple enough, and natural checks on the results abound. This method requires, however, the quantities $\mathrm{D}^q\Pi^0_0$ where $q-1$ is equal to the highest power of e or e_1, which has to be included. Thus in actual work we must compute—

$$2\Pi^1_1,\ 8\Pi^2_2,\ 48\Pi^3_3 \ldots \text{ \&c.}$$
$$\mathrm{D}2\Pi^1_1,\ \mathrm{D}8\Pi^2_2,\ \mathrm{D}48\Pi^3_3 \ldots \text{ \&c.}$$
$$\mathrm{D}^2 2\Pi^1_1,\ \mathrm{D}^2 8\Pi^2_2,\ \text{\&c.} \ldots \text{ \&c.}$$
$$\ldots \quad \ldots \quad \ldots \quad \ldots$$

The presence of the D operator in no way alters the tables, thus—

$$0 = \quad (-2i - \mathrm{D})\Pi_{\circ}^{\circ} - 2\Pi_{i}^{\circ}.$$
$$0 = \mathrm{D}^{q}(-2i - \mathrm{D})\Pi_{\circ}^{\circ} - \mathrm{D}^{q}2\Pi_{i}^{\circ}.$$

And so on.

As pointed out in the tables, the forms for $\Pi_{-n,n'}^{n,n'}$ or $\Pi_{n,-n'}^{n,-n'}$ are included. It must be remembered that such an operator as Π_{-i}^{i} cannot act alone; in actual work it will be joined to another of at least the same order but with a positive suffice, the final form being $\Pi_{-i,i}^{i,i}$ or $\Pi_{-i,2i}^{i,2i}$, and so on. In fact, although of primary form, such are closely connected with the secondary terms. As the secondary, tertiary, and higher terms are seldom required, it is, as already mentioned, advisable to make them dependent on the first order terms. In the tertiary terms we first meet with the quantity i^2, but it can be eliminated by the introduction of an iD operator which will make the numerical work simpler.

The tables for the secondary terms (Tables II.A and II.B and III.A and III.B) require no further explanation—the examples attached to each show their use.

The paper concludes with a symbolic expression for the non-periodic or secular part of the perturbative function, which by simple multiplications will give the expansion to any powers of the excentricities and mutual inclination. Examples are added, which can be compared with the known results given by Newcomb and other investigators.

The happy introduction by Newcomb of the two operators—one of which is purely symbolical—D and Π, has vastly simplified the development of the perturbative function. The curious properties of the D operator have been dealt with in the *Monthly Notices* of the Royal Astronomical Society for June and December, 1909.

JOHANNESBURG,
September 5, 1911.

TABLE I.A. $\Pi^{n,n'}_{m,m'}$ for n.

...	...	...	...	...	...	...	...	...
$645120\Pi^{0,7}_{0,7}$	$1290240\Pi^{1,7}_{1,7}$	...	...	...	...	...	...	...
$46080\Pi^{0,6}_{0,6}$	$92160\Pi^{1,6}_{1,6}$	$364440\Pi^{2,6}_{2,6}$	...	...	...	...	...	...
$3840\Pi^{0,5}_{0,5}$	$7680\Pi^{1,5}_{1,5}$	$30720\Pi^{2,5}_{2,5}$	$184320\Pi^{3,5}_{3,5}$	...	...	...	...	...
$384\Pi^{0,4}_{0,4}$	$768\Pi^{1,4}_{1,4}$	$3072\Pi^{2,4}_{2,4}$	$18432\Pi^{3,4}_{3,4}$	$147576\Pi^{4,4}_{4,4}$	...	...	...	...
$48\Pi^{0,3}_{0,3}$	$96\Pi^{1,3}_{1,3}$	$384\Pi^{2,3}_{2,3}$	$2304\Pi^{3,3}_{3,3}$	$18432\Pi^{4,3}_{4,3}$	$184320\Pi^{5,3}_{5,3}$	...	...	...
$8\Pi^{0,2}_{0,2}$	$16\Pi^{1,2}_{1,2}$	$64\Pi^{2,2}_{2,2}$	$384\Pi^{3,2}_{3,2}$	$3072\Pi^{4,2}_{4,2}$	$30720\Pi^{5,2}_{5,2}$	$368640\Pi^{6,2}_{6,2}$	...	...
$2\Pi^{0,1}_{0,1}$	$4\Pi^{1,1}_{1,1}$	$16\Pi^{2,1}_{2,1}$	$96\Pi^{3,1}_{3,1}$	$768\Pi^{4,1}_{4,1}$	$7680\Pi^{5,1}_{5,1}$	$92160\Pi^{6,1}_{6,1}$	$1290240\Pi^{7,1}_{7,1}$	...
$\Pi^{0,0}_{0,0}$	$2\Pi^{1,0}_{1,0}$	$8\Pi^{2,0}_{2,0}$	$48\Pi^{3,0}_{3,0}$	$384\Pi^{4,0}_{4,0}$	$3840\Pi^{5,0}_{5,0}$	$46080\Pi^{6,0}_{6,0}$	$645120\Pi^{7,0}_{7,0}$	$10321920\Pi^{8,0}_{8,0}$
$-2i-\mathrm{D}$	-1							
i	$-2i+3-\mathrm{D}$	-1						
$2i$	$1.(2i-1)/1$	$-2i+6-\mathrm{D}$	-1					
$9i$	$2.(3i-1)/1$	$1.3.(2i-2)/2$	$-2i+9-\mathrm{D}$	-1				
$64i$	$9.(4i-1)/1$	$2.4(3i-2)/2$	$1.6.(2i-3)/3$	$-2i+12-\mathrm{D}$	-1			
$625i$	$64(5i-1)/1$	$9.5(4i-2)/2$	$2.10.(3i-3)/3$	$1.10(2i-4)/4$	$-2i+15-\mathrm{D}$	-1		
$7776i$	$625(6i-1)/1$	$64.6(5i-2)/2$	$9.15(4i-3)/3$	$2.20(3i-4)/4$	$1.15.(2i-5)/5$	$-2i+18-\mathrm{D}$	-1	
$117649i$	$7776(7i-1)/1$	$625.7(6i-2)/2$	$64.21(5i-3)/3$	$9{\cdot}35(4i-4)/4$	$2.35\,(2i-5)/5$	$1.21.(2i-6)/6$	$2i+21-\mathrm{D}$	-1
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

Example.

$$3840\Pi_5^5 = 64i\Pi_0^0 + 9(4i-1)2\Pi_1^1 + 4(3i-2)8\Pi_2^2 + 2(2i-3)48\Pi_3^3 + (-2i+12-\mathrm{D})384\Pi_4^4.$$

This example may be compared with the formulæ for the same example given by Newcomb and Chessin (*Astron. Journ.*, No. 442, p. 74). The operator D^m can, if necessary, be affixed to each term.

The same factors will also occur in the derivation of $\Pi_{5,n'}^{5,n'}$.

Construction and Extension of the Table.

Top portion. The successive factors are 2, 4, 6, 8, 10, &c. This portion can be extended indefinitely. The limit adopted is $n+n'=8$.

Lower portion. First column. The successive factors of i are of the form p^{p-1}, viz., 2^1, 3^2, 4^3, &c. These numbers reappear in the successive columns, but lowered one line each time.

The continuation of the remaining factors and divisors is very obvious. The numbers of the figurate table will be recognised, viz.:—

1	2	3	4	5	6	7	.....
1	3	6	10	15	21	28	.....
1	4	10	20	35	.....		
1	5	15	35	70	.....		
1	6	21	.....				

TABLE I.B. $\Pi^{n,n'}_{n,n'}$ for n'.

Only a few lines of this table need be given. It can be constructed from Table I.A by replacing—

i by $-i$
$-\mathrm{D}$ by $1+\mathrm{D}$

...	...	...	...	...	...	...	...	...
$8\Pi^{2,0}_{2,0}$	$16\Pi^{2,1}_{2,1}$	$64\Pi^{2,2}_{2,2}$	...	...	...	...	...	...
$2\Pi^{1,0}_{1,0}$	$4\Pi^{1,1}_{1,1}$	$16\Pi^{1,2}_{1,2}$	$96\Pi^{1,3}_{1,3}$	...	...	...	...	...
$\Pi^{0,0}_{0,0}$	$2\Pi^{0,1}_{0,1}$	$8\Pi^{0,2}_{0,2}$	$48\Pi^{0,3}_{0,3}$	$384\Pi^{0,4}_{0,4}$	...	...	...	...
$2i+1+\mathrm{D}$	-1							
$-i$	$2i+4+\mathrm{D}$	-1						
$-2i$	$-1.(2i+1)/1$	$2i+7+\mathrm{D}$	-1					
$-9i$	$-2(3i+1)/1$	$-1.3.(2i+2)/2$	$2i+10+\mathrm{D}$	-1				
...	...	...	...	...	...			

Example.

By Table I.B. $64\Pi^{2,2}_{2,2} = -i8\Pi^{2,0}_{2,0} + (+2i+4+\mathrm{D})16\Pi^{2,1}_{2,1}$
By Table I.A. $64\Pi^{2,2}_{2,2} = \ i8\Pi^{0,2}_{0,2} + (-2i+3-\mathrm{D})16\Pi^{1,2}_{1,2}$

This example is chosen because it shows how many of the higher terms can be independently calculated in duplicate.

TABLE II.A. $\Pi^{n\,n'}_{n.n'}$.

This is a secondary table. It is constructed from Table I.A by replacing—

$$i \text{ by } -i,$$

and the first of the lower suffices—

$$n \text{ by } -n.$$

Only a few lines of this table need be given, as it can be formed from Table I.A so easily.

$48\Pi^{0.3}_{0.3}$	$96\Pi^{1.3}_{-1.3}$	...	...	...	...	...	...	...
$8\Pi^{0.2}_{0.2}$	$16\Pi^{1.2}_{-1.2}$	$64\Pi^{2.2}_{-2.2}$	...	...	...	...	...	...
$2\Pi^{0.1}_{0.1}$	$4\Pi^{1.1}_{-1.1}$	$16\Pi^{2.1}_{-2.1}$	$96\Pi^{3.1}_{-3.1}$	...	...	...	...	...
$\Pi^{0.0}_{0.0}$	$2\Pi^{1.0}_{-1.0}$	$8\Pi^{2.0}_{-2.0}$	$48\Pi^{3.0}_{-3.0}$	$384\Pi^{4.0}_{-4.0}$	...	...	...	...

$2i-D$	-1							
$-i$	$2i+3-D$	-1						
$-2i$	$-1(2i+1)$	$2i+6-D$	-1					
$-9i$	$-2(3i+1)$	$-1.3(2i+2)/2$	$2i+9-D$	-1				
$-64i$	$-9(4i+1)$	$-2.4(3i+2)/2$	$-1.6.(2i+3)/3$	$2i+12-D$	-1			

Example.

Newcomb's formula is—

$$96\Pi^{1.3}_{-1.3} = (2i-D)48\Pi^{0.3}_{0.3}.$$

$$\begin{aligned} 96\Pi^{1.3}_{-1.3} = {} & +16i^4+84i^3+130i^2+54i+0 \\ & +(16i^3+48i^2+11i-27)D \\ & +(-21i-38)D_2 \\ & +(-4i-12)D_3 \\ & -D_4 \end{aligned}$$

TABLE II.B. $\Pi_{n.-n'}^{n.n'}$.

This is a secondary table, constructed from Table I.A by replacing—

i by $-i$,

or from Table I.A by replacing—

$-\mathrm{D}$ by $1+\mathrm{D}$.

As with Table II A, a few lines only need be given.

$48\Pi_{3.0}^{3.0}$	$96\Pi_{3.-1}^{3.1}$	...	...	...	...	...	...	...
$8\Pi_{2.0}^{2.0}$	$16\Pi_{2.-1}^{2.1}$	$64\Pi_{2.-2}^{2.2}$	...	...	...	...	...	...
$2\Pi_{1.0}^{1.0}$	$4\Pi_{1.-1}^{1.1}$	$16\Pi_{1.-2}^{1.2}$	$96\Pi_{1.-3}^{1.3}$	...	...	...	...	...
$\Pi_{0.0}^{0.0}$	$2\Pi_{0.-1}^{0.1}$	$8\Pi_{0.-2}^{0.2}$	$48\Pi_{0.-3}^{0.3}$	$384\Pi_{0.-4}^{0.4}$	...	...	...	...
$-2i+1+\mathrm{D}$	-1							
i	$-2i+4+\mathrm{D}$	-1						
$2i$	$1.(2i-1)$	$-2i+7+\mathrm{D}$	-1					
$9i$	$2.(3i-1)$	$1.3.(2i-2)/2$	$-2i+10+\mathrm{D}$	-1				
...	...	...	...	...	...			

Example.

$$16\Pi_{1.-2}^{1.1}=i2\Pi_{1}^{1}+(-2i+4+\mathrm{D})4\Pi_{.-1}^{1.1}.$$

N.B.—$\Pi_{-n.n'}^{n.n'}=\Pi_{n.-n'}^{n.n'}$ if i is replaced by $-i$.

TABLE III.A. $\Pi^{n,\ n'}_{p,\ p'}$.

				...	...	...	...	...	...	...	...	...
				...	...	...	...	...	...	...	...	...
				$384\Pi^{0,4}_{0,4}$	...	...	...	...	...	...	...	...
				$48\Pi^{0,3}_{0,3}$	$96\Pi^{1,3}_{1,3}$	$384\Pi^{2,3}_{2,3}$	$2304\Pi^{3,3}_{3,3}$	$18432\Pi^{4,3}_{4,3}$	...	...	...	...
				$8\Pi^{0,2}_{0,2}$	$16\Pi^{1,2}_{1,2}$	$64\Pi^{2,2}_{2,2}$	$384\Pi^{3,2}_{3,2}$	$3072\Pi^{4,2}_{4,2}$	$30720\Pi^{5,2}_{5,2}$	$368640\Pi^{6,2}_{6,2}$	...	...
				$2\Pi^{0,1}_{0,1}$	$4\Pi^{1,1}_{1,1}$	$16\Pi^{2,1}_{2,1}$	$96\Pi^{3,1}_{3,1}$	$768\Pi^{4,1}_{4,1}$	$7680\Pi^{5,1}_{5,1}$	$92160\Pi^{6,1}_{6,1}$	$1290240\Pi^{7,1}_{7,1}$	...
				$\Pi^{0,0}_{0,0}$	$2\Pi^{1,0}_{1,0}$	$8\Pi^{2,0}_{2,0}$	$48\Pi^{3,0}_{3,0}$	$384\Pi^{4,0}_{4,0}$	$3840\Pi^{5,0}_{5,0}$	$46080\Pi^{6,0}_{6,0}$	$645120.\Pi^{7,0}_{7,0}$	$10321920\Pi^{8,0}_{8,0}$
$96\Pi^{1,3}_{-1,3}$	$16\Pi^{1,2}_{-1,2}$	$4\Pi^{1,1}_{-1,1}$	$2\Pi^{1,0}_{-1,0}$	$-2D$	-1							
$192\Pi^{2,3}_{0,3}$	$32\Pi^{2,2}_{0,2}$	$8\Pi^{2,1}_{0,1}$	$4\Pi^{2,0}_{0,0}$	$-i$	$2(1-D)$	-1						
$768\Pi^{3,3}_{1,3}$	$128\Pi^{3,2}_{1,2}$	$32\Pi^{3,1}_{1,1}$	$16\Pi^{3,0}_{1,0}$	0	$-2(i-1)$	$2(2-D)$	-1					
$4608\Pi^{4,3}_{2,3}$	$768\Pi^{4,2}_{2,2}$	$192\Pi^{4,1}_{2,1}$	$96\Pi^{4,0}_{2,0}$	$2i$	0	$-2.3.(i-2)/2$	$2(3-D)$	-1				
$36864\Pi^{5,3}_{3,3}$	$6144\Pi^{5,2}_{3,2}$	$1536\Pi^{5,1}_{3,1}$	$768\Pi^{5,0}_{3,0}$	$20i$	$2(4i-1)$	0	$-2.6(i-3)/3$	$2(4-D)$	-1			
...	$61440\Pi^{6,2}_{4,2}$	$15360\Pi^{6,1}_{4,1}$	$7680\Pi^{6,0}_{4,0}$	$226i$	$20(5i-1)$	$2.5.(4i-2)/2$	0	$-2.10(i-4)/4$	$2(5-D)$	-1		
...	...	$184320\Pi^{7,1}_{5,1}$	$92160\Pi^{7,0}_{5,0}$	$3052i$	$226(6i-1)$	$20.6.(5i-2)/2$	$2.15(4i-3)/3$	0	$-2.15(i-5)/5$	$2(6-D)$	-1	
...	...	...	$1290240\Pi^{8,0}_{6,0}$	$48674i$	$3052(7i-1)$	$226.7(6i-2)/2$	$20.21.(5i-3)/3$	$2.35(4i-4)/4$	0	$-2.21.(i-6)/6$	$2(7-D)$	-1

The indefinite extension of this table is on the same lines as that of Table I.A. The factors of $2i$ in the first body-column being of the form $(p+1)^p - 2p^p$.

Examples. $96\Pi_{-1,3}^{1,3} = -2D48\Pi_{0,3}^{0,3} - 96\Pi_{1,3}^{1,3}$. (See for this example, also Table II.A.)

$8\Pi_{0,1}^{2,1} = -i2\Pi_{0,1}^{0,1} + 2(1-D)4\Pi_{1,1}^{1,1} - 16\Pi_{2,1}^{2,1}$.

TABLE IIIB. $\Pi^{n,n'}_{n,n'-2}$.

This table is derived from Table III.A by changing—

$-i$ into i
$-\mathrm{D}$,, $1+\mathrm{D}$

Only a few lines need be given.

					$384\Pi^{4,0}_{4,0}$	$768\Pi^{4,1}_{4,1}$	...	...
					$48\Pi^{3,0}_{3,0}$	$96\Pi^{3,1}_{3,1}$	...	...
					$8\Pi^{2,0}_{2,0}$	$16\Pi^{2,1}_{2,1}$	$64\Pi^{2,2}_{2,2}$	...
					$2\Pi^{1,0}_{1,0}$	$4\Pi^{1,1}_{1,1}$	$16\Pi^{1,2}_{1,2}$	$96\Pi^{1,3}_{1,3}$
					$\Pi^{0,0}_{0,0}$	$2\Pi^{0,1}_{0,1}$	$8\Pi^{0,2}_{0,2}$	$48\Pi^{0,3}_{0,3}$
$768\Pi^{4,1}_{4,-1}$	$96\Pi^{3,1}_{3,-1}$	$16\Pi^{2,1}_{2,-1}$	$4\Pi^{1,1}_{1,-1}$	$2\Pi^{0,1}_{0,-1}$	$2(1+\mathrm{D})$	-1		
$1536\Pi^{4,2}_{4,0}$	$192\Pi^{3,2}_{3,0}$	$32\Pi^{2,2}_{2,0}$	$8\Pi^{1,2}_{1,0}$	$4\Pi^{0,2}_{0,0}$	i	$2(2+\mathrm{D})$	-1	
$6144\Pi^{4,3}_{4,1}$	$768\Pi^{3,3}_{3,1}$	$128\Pi^{2,3}_{2,1}$	$32\Pi^{1,3}_{1,1}$	$16\Pi^{0,3}_{0,1}$	0	$2(i+1)$	$2(3+\mathrm{D})$	-1
$36864\Pi^{4,4}_{4,2}$	$4608\Pi^{3,4}_{3,2}$	$768\Pi^{2,4}_{2,2}$	$192\Pi^{1,4}_{1,2}$	$96\Pi^{0,4}_{0,2}$	...	...	...	...

Example.

$$128\Pi^{2,3}_{2,1} = (2i+1)16\Pi^{2,1}_{2,1} + 2(3+\mathrm{D})64\Pi^{2,2}_{2,2} - 384\Pi^{2,3}_{2,3}.$$

F = Non-Periodic Part of the Elliptic Perturbative Function.

$$\begin{aligned}
&\tfrac{1}{2}E_0E_0'a_1A_0 && - \sigma^2[&& EE'\cos(w+w_1)]\,a_1B_0 + \sigma^4[&& E_2E_2'\cos(2w+2w_1)]\,a_1C_0 - \&c.\\
&- E_1E_1'a_1A_1\cos(w-w_1) && + \sigma^2[&& E_2\cos 2w + E_2'\cos(2w_1)]\,a_1B_1 - \sigma^4[E_3E'\cos(3w+w_1) + EE_3'\cos(w+3w_1)]\,a_1C_1 + \&c.\\
&+ E_2E_2'a_1A_2\cos(2w-2w_1) && - \sigma^2[&& E_3E'\cos(3w-w_1) + EE_3'\cos(w-3w_1)]\,a_1B_2 + \sigma^4[&& E_4\cos 4w + E_4'\cos(4w_1)]\,a_1C_2 - \&c.\\
&- E_3E_3'a_1A_3\cos(3w-3w_1) && + \sigma^2[E_4E_2'\cos(4w-2w_1) + E_2E_4'\cos(2w-4w_1)]\,a_1B_3 && - \&c.\\
&+ E_4E_4'a_1A_4\cos(4w-4w_1) && - \&c.\\
&- \&c.
\end{aligned}$$

Indefinite Extension.

First line. The general law is disclosed by the terms written; thus the next term is $-\sigma^6[E_3E_3'\cos 3(w+w_1)]\,a_1D_0$, which is at least of the 12th order. For symmetry's sake the symbolical operators are separated from their objects, the a_1B_0, &c.

Second line. To each angle in the first line both add and subtract $(w-w_1)$. In the first column these will sum into $\cos(w-w_1)$, in the next column into $\cos 2w$ and $\cos 2w_1$, and so on. The symbolical operator connected with any angle $(nw \pm n_1w_1)$ is $E_nE_{n_1}'$. The signs will be negative for odd values of E′ and positive for even values. The suffices of a_1A_0, a_1B_0, &c., increase by one unit.

Third line. To each angle in the first line both add and subtract $2w-2w_1$, &c., &c.

Expressions for the Symbolical Operators E and E′.

$$E_0 = \left[1 + \frac{(D+1)D}{1}\left(\frac{e}{2}\right)^2 + \frac{1}{2!}\frac{(D+1)D(D-1)(D-2)}{1.\ 2.}\left(\frac{e}{2}\right)^4 + \frac{1}{3!}\frac{(D+1)D(D-1)(D-2)(D-3)(D-4)}{1.\ 2.\ 3.}\left(\frac{e}{2}\right)^6 + \&c.\right]$$

$$E_1 = \left(\frac{e}{2}\right)(D+2)\left[1 + \frac{D(D-1)}{2}\left(\frac{e}{2}\right)^2 + \frac{1}{2!}\frac{D(D-1)(D-2)(D-3)}{2.\ 3}\left(\frac{e}{2}\right)^4 + \frac{1}{3!}\frac{D(D-1)(D-2)(D-3)(D-4)(D-5)}{2.\ 3.\ 4}\left(\frac{e}{2}\right)^6 + \&c.\right]$$

$$E_2 = \frac{1}{2!}\left(\frac{e}{2}\right)^2(D+3)(D+2)\left[1 + \frac{(D-1)(D-2)}{3}\left(\frac{e}{2}\right)^2 + \frac{1}{2!}\frac{(D-1)(D-2)(D-3)(D-4)}{3.\ 4}\left(\frac{e}{2}\right)^4 + \&c.\right]$$

$$E_3 = \frac{1}{3!}\left(\frac{e}{2}\right)^3(D+4)(D+3)(D+2)\left[1 + \frac{(D-2)(D-3)}{4}\left(\frac{e}{2}\right)^2 + \frac{1}{2!}\frac{(D-2)(D-3)(D-4)(D-5)}{4.\ 5}\left(\frac{e}{2}\right)^4 + \&c.\right]$$

$$E_4 = \frac{1}{4!}\left(\frac{e}{2}\right)^4(D+5)(D+4)(D+3)(D+2)\left[1 + \frac{(D-3)(D-4)}{5}\left(\frac{e}{2}\right)^2 + \&c.\right]$$

&c. &c.

$$E'_0 = \left[1 + \frac{D(D+1)}{1}\left(\frac{e_1}{2}\right)^2 + \frac{1}{2!}\frac{D(D+1)(D+2)(D+3)}{1.\ 2.}\left(\frac{e_1}{2}\right)^4 + \frac{1}{3!}D(D+1)(D+2)(D+3)(D+4)(D+5)\left(\frac{e_1}{2}\right)^6 + \&c.\right]$$

$$E'_1 = \left(\frac{e_1}{2}\right)(D-1)\left[1 + \frac{(D+1)(D+2)}{2}\left(\frac{e_1}{2}\right)^2 + \frac{1}{2!}\frac{(D+1)(D+2)(D+3)(D+4)}{2.\ 3}\left(\frac{e_1}{2}\right)^4 + \&c.\right]$$

$$E'_2 = \frac{1}{2!}\left(\frac{e_1}{2}\right)^2(D-2)(D-1)\left[1 + \frac{(D+2)(D+3)}{3}\left(\frac{e_1}{2}\right)^2 + \&c.\right]$$

$$E'_3 = \frac{1}{3!}\left(\frac{e_1}{2}\right)^3(D-3)(D-2)(D-1)\left[1 + \&c.\right]$$

&c. &c.

Examples.

Compare with these the equivalent expressions given by Newcomb, Secular Variations of the Four Inner Planets (*Astron. Papers of the American Ephemeris*, vol. v., pp. 306–307).

(1) $\sigma^2 \mathrm{E}'_2 a_1 \mathrm{B}_1 \cos 2w_1$

$$\mathrm{E}'_2 = \frac{e_1^2}{8}(\mathrm{D}-2)(\mathrm{D}-1) + \frac{e_1^4}{96}(\mathrm{D}-2)(\mathrm{D}-1)(\mathrm{D}+2)(\mathrm{D}+3) + \text{ \&c.}$$

giving—

$$+\sigma\frac{e_1^2}{8}(2-3\mathrm{D}+\mathrm{D}^2)a_1\mathrm{B}_1\cos 2w_1 + \sigma^2\frac{e_1^4}{29}(12-8\mathrm{D}-7\mathrm{D}^2+2\mathrm{D}^3+\mathrm{D}^4)a_1\mathrm{B}_1\cos 2w_1 + \text{ \&c.}$$

(2) $-\mathrm{E}_1\mathrm{E}'_1 a_1 \mathrm{A}_1 \cos(w - w_1)$

$$\mathrm{E}_1 = \frac{e}{2}(\mathrm{D}+2) + \frac{e^3}{16}(\mathrm{D}+2)\mathrm{D}(\mathrm{D}-1) + \frac{e^5}{768}(\mathrm{D}+2)\mathrm{D}(\mathrm{D}-1)(\mathrm{D}-2)(\mathrm{D}-3) + \text{ \&c.}$$

$$\mathrm{E}'_1 = \frac{e_1}{2}(\mathrm{D}-1) + \frac{e_1^3}{16}(\mathrm{D}-1)(\mathrm{D}+1)(\mathrm{D}+2) + \frac{e_1^5}{768}(\mathrm{D}-1)(\mathrm{D}+1)(\mathrm{D}+2)(\mathrm{D}+3)(\mathrm{D}+4) + \text{ \&c.}$$

hence—

$$\mathrm{E}_1\mathrm{E}'_1 = \frac{ee_1}{4}(-2+\mathrm{D}+\mathrm{D}^2) + \frac{e^3e_1}{32}(2\mathrm{D}-3\mathrm{D}^2+0\mathrm{D}^3+\mathrm{D}^4) + \text{ \&c., \&c.}$$

SOME OBSERVATIONS CONCERNING THE TRANSMISSION OF EAST COAST FEVER BY TICKS.

By Dr. Arnold Theiler, C.M.G., *Acting Director of Veterinary Research.*

(Read August 16, 1911.)

It has been proved that *Theileria parva*, the cause of East Coast Fever, can be transmitted by at least five different species of ticks of the genus *Rhipicephalus* (viz., *Rh. appendiculatus*, *Rh. evertsi*, *Rh. nitens*, and *Rh. capensis*). Of these, *Rh. appendiculatus* is the commonest in South Africa and in the regions in which East Coast Fever is known generally (Uganda, British, and German East Africa). They were almost exclusively used in my experience on East Coast Fever.

The following observations, which were made in connection with experiments undertaken for other purposes (mainly to get material for the artificial transmission of the disease, and to test the resulting immunity), form an interesting addition to and confirmation of facts which have already been established concerning the transmission of East Coast Fever by means of ticks.

EXPERIMENT No. 1.

"A." TO DEMONSTRATE THE FACT THAT BROWN TICK IMAGINES, WHICH AS LARVÆ HAD BECOME INFECTED WITH EAST COAST FEVER, AND HAD TRANSMITTED THE DISEASE IN THEIR NYMPHAL STAGE, ARE NO LONGER INFECTIVE FOR SUSCEPTIBLE CATTLE.

(*a*) Rhipicephalus appendiculatus, imago (Ref. No. 268).

Note.—The adult females originated from Natal on January 12, 1910; the eggs were laid on January 18, 1910, and hatched into larvæ in the laboratory on February 18, 1910.

Infecting the Ticks.—The larvæ were fed on Heifer 923 from March 20 to 23, 1910, that is, from the 20th to 23rd day of the disease, and at a

time when the parasites of East Coast Fever were very frequent in the blood.

Cleaning the Ticks.—The larvæ moulted in due time, and the nymphæ were placed on Cow 596 on April 7, 1910. Cow 596 developed the disease after an incubation time of 15 days, and was killed for experimental purposes on the 12th day of the East Coast Fever illness.

Remarks.—The nymphæ collected as engorged larvæ off Heifer 923 whilst undergoing an East Coast Fever reaction proved to be infective for Cow 596.

Note.—The nymphæ which communicated the disease to Cow 596 engorged and were collected off this cow from April 13 to 15, 1910. They moulted into adults on May 20, 1910, and were used for the infestation of cattle Nos. 1022 and 1060 (*vide* Experiment No. 1 "C," Nos. 21 and 22).

(*b*) RHIPICEPHALUS APPENDICULATUS, imagines (Ref. No. 309).

Note.—The engorged females originated from Natal on December 9, 1909. The eggs were laid on December 24, 1909, and the larvæ hatched out on January 30, 1910.

Infecting the Ticks.—The larvæ were fed on Calf 700 from February 27, 1910, and dropped between March 2nd and 7th, that is, from the 7th and 8th days of the disease, and at a time when *Theileria parva* were frequently met with in the blood.

Cleaning the Ticks.—The engorged larvæ moulted on March 17, 1910, and the nymphæ were placed on Calf 917 on March 30, 1910. This calf developed East Coast Fever after the usual period and died; the examination of the blood proved the presence of *Theileria parva*, and the glands contained Agamonts and Gamonts in large numbers.

Remarks.—The ticks which as larvæ were fed on Calf 700 during the time of the East Coast Fever reaction proved virulent for Calf 917 in their nymphal stage.

Note.—The nymphæ which communicated the disease to Calf 917 engorged and were collected from April 3 to 7, 1910, namely, a week after infestation. They moulted into adults on May 4, 1910, and were placed on Heifer 1088 on December 15, 1910, and on Calf 1145 on January 6, 1911, in order to test their infectivity (*vide* later Experiment No. 1 "C," Nos. 23 and 24).

(*c*) RHIPICEPHALUS APPENDICULATUS, imagines (Ref. No. 335).

Infecting the Ticks.—The larvæ which originated from females collected in Natal on December 19, 1909; the eggs were laid on December 24, 1909, and the larvæ hatched out on January 30, 1910. On February

27, 1910, the larvæ were placed on Calf 917. (Calf 917 contracted East Coast Fever from the ticks of Calf 700—*vide* sub-head (*b*).) The larvæ were collected off Calf 917 between April 11 and 14, 1910, at a time when *Theileria parva* were frequently met with in the blood and the plasma bodies were present in the organs.

Cleaning the Ticks.—The engorged larvæ moulted in due time, together with nymphæ off Cattle 700 (Ref. No. 309) and off 923 (Ref. No. 268) were used for the infestation of the following eight cattle: Nos. 561, 908, 919, 1101, 914, 1012, 1026, and 1040.

(*c*) RHIPICEPHALUS APPENDICULATUS (Ref. Nos. 309, 268, and 335).

1. Heifer 561 was infected on July 26, 1910, with brown nymphæ as above, and developed East Coast Fever after an incubation period of 12 days. This heifer was killed for experimental purposes 20 days later, when microscopical examination proved the presence of *Th. parva* in the blood and the plasma bodies in the glands.

Remarks.—The ticks which as larvæ had fed on Cattle 700, 917, and 923, proved virulent in their nymphal stage for Heifer 561.

Note.—The engorged brown nymphæ were all collected by August 2, 1910. They moulted into adults on September 19, 1910, and were placed on Heifer 1088 on December 15, 1910, and on Calf 1145 on January 6, 1911 (*vide* Experiment 1 "C," Nos. 23 and 24).

2. Heifer 908 was infested on July 26, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 355), as above. This heifer developed East Coast Fever after an incubation time of 13 days, and was killed for experimental purposes on August 22, 1910, after an illness of 14 days. The blood contained *Th. parva*, and in the glands and spleen plasma granules were frequently found.

Note.—The engorged brown nymphæ were collected by August 2, 1910, and had moulted into adults on September 19, 1910; the adults were placed on Heifer 1088 on December 15, 1910, and on Calf 1145 on January 6, 1911, in order to test their infectivity (*vide* later Experiment No. 1 "C," Nos. 23 and 24).

3. Calf 919 was infested on June 27, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. An East Coast Fever reaction set in after an incubation time of 14 days, and the calf died on July 28, 1910, the 16th day of illness. The blood contained *Th. parva* in large numbers, and plasma bodies were frequently met with in the glands.

Note.—The engorged brown nymphæ were all collected by July 12, 1910, and moulted into adults in due time, when they were placed on

Heifer 1088 and Calf 1145 in order to test their infectivity (*vide* later Experiment No. 1 "C," Nos. 23 and 24).

4. Heifer 914 was infested on June 28, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. It developed East Coast Fever after an incubation time of 13 days and recovered. The blood contained *Th. parva*, and plasma bodies were found in the glands.

Note.—The engorged brown nymphæ were all collected by July 12, 1910, and moulted into adults by September 19, 1910; they were placed on Heifer 1088 and Calf 1145 on December 15, 1910, and on January 6, 1911, respectively, in order to test their infectivity (*vide* later Experiment No. 1 "C," Nos. 23 and 24).

5. Heifer 1012 was infested on June 27, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. It developed East Coast Fever after an incubation time of 12 days, and died on July 26, 1910. The blood was found to contain *Th. parva*, and plasma bodies were noted in the glands.

Note.—The engorged nymphæ were collected in due time, and were finally placed on Heifer 1088 and on Calf 1145 in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 23 and 24).

6. Heifer 1011 was infested on June 27, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. After an incubation time of 13 days an East Coast Fever reaction set in, and the heifer was killed for experimental purpose on the 8th day of the disease (July 18, 1910). The blood contained *Th. parva* in rare numbers, but plasma bodies were found to be very frequent in the glands.

Note.—The engorged nymphæ were collected in due time, and had moulted by September 19, 1910. They were placed on Heifer 1088 on December 15, 1910, and on Calf 1145 on January 6, 1911, in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 23 and 24).

7. Ox 1026 was infested on June 27, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. East Coast Fever developed after an incubation time of 12 days, and the ox was killed on the 16th day of illness for experimental purposes (July 25, 1910). The blood contained *Th. parva*, and the glands showed the presence of plasma bodies in large numbers.

Note.—The engorged nymphæ were collected in due time, and moulted into adults by September 19, 1910; they were used for the infestation of Heifer 1088 and Calf 1145 on December 15, 1910, and January 6, 1911,

respectively, in order to test their infectivity (*vide* Experiment No. 1 "C," Nos 23 and 24).

8. Ox 1040 was infested on June 27, 1910, with brown nymphæ off Cattle 700, 917, and 923 (Ref. Nos. 309, 335, and 268), as above. Ox 1040 developed East Coast Fever after an incubation time of 13 days, and died on the 15th day of illness (July 25, 1910). The blood showed a strong infection of *Th. parva*, but plasma bodies were found in rare numbers only in the glands.

Note.—The nymphæ engorged in due time, and moulted into adults by September 19, 1910; they were used for the infestation of Heifer 1088 and Calf 1145 (*vide* Experiment No. 1 "C," Nos. 23 and 24).

EXPERIMENT No. 1 (*continued*).

"B." TO DEMONSTRATE THE FACT THAT BROWN TICK IMAGINES, WHICH AS LARVÆ HAD BECOME INFECTED WITH EAST COAST FEVER, AFTER HAVING PASSED THEIR NYMPHAL STAGE ON CATTLE RENDERED IMMUNE TO EAST COAST FEVER BY INOCULATION, NO LONGER TRANSMIT THE DISEASE TO SUSCEPTIBLE CATTLE.

(*e*) RHIPICEPHALUS APPENDICULATUS (Ref. Nos. 309, 268, and 335).

(See previous sub-head (*d*).)

Note.—The animals referred to later (Nos. 829, 883, 836, 895, 1047, 1033, 871, 621, 679, and 615) had all been rendered immune to East Coast Fever by inoculation, details of which were given in the Annual Report of the Government Veterinary Bacteriologist for 1909–10, under the title of "The Artificial Transmission of East Coast Fever" (see pp. 1–55).

9. Ox 829 was rendered immune to East Coast Fever by inoculation (see above).

Infested on March 24, 1910, with brown nymphæ off Calf 700 (Ref. No. 309).

Note.—The engorged nymphæ were collected on March 30, 1910; they moulted into adults on April 21, 1910, and were placed on Heifers 1057 and 1058 on August 5, 1910, in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 25 and 26).

10. Heifer 883 was rendered immune by inoculation (*vide* above).

Infested on March 24, 1910, with brown nymphæ off Calf 700 (Ref. No. 309).

Note.—The engorged nymphæ were collected on March 30, 1910; they moulted into adults on April 21, 1910, and in their adult stage were used for the infestation of Heifers 1057 and 1058 (*vide* Experiment No. 1 " C," Nos. 25 and 26), on August 5, 1910, in order to test their infectivity.

11. Heifer 836 rendered immune by inoculation (*vide* above).

Infested on March 24, 1910, with brown nymphæ off Calf 700 (Ref. No. 309).

Note.—The engorged nymphæ dropped on March 30, 1910, and moulted into adults on April 21, 1910; the adults were placed on Heifers 1057 and 1058 on August 5, 1910, in order to test their infectivity (*vide* Experiment No. 1 " C," Nos. 25 and 26).

12. Heifer 895 was rendered immune by inoculation (*vide* above).

Infested on March 24, 1910, with brown nymphæ off Calf 700 (Ref. No. 309).

Note.—The engorged nymphæ dropped on March 30, 1910, and moulted into adults on April 21, 1910; they were placed on Heifers 1057 and 1058 on August 5, 1910, in order to test their infectivity (*vide* Experiment No. 1 " C," Nos. 25 and 26).

13. Ox 1047 rendered immune by inoculation (*vide* above).

Infested on July 28, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected on August 2, 1910, and moulted into adults on September 19, 1910; the adults were used for the infestation of Heifer 1088 and Calf 1145 (*vide* Experiment No. 1 " C," Nos. 25 and 26) in order to test their infectivity.

14. Cow 1033 was rendered immune by inoculation (*vide* above).

Infested on July 27, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected on August 2, 1910, and moulted into adults on September 19, 1910; later they were placed on Cattle 1088 and 1145 (*vide* Experiment No. 1 " C," Nos. 25 and 26) in order to test their infectivity.

15. Heifer 871 was rendered immune by inoculation (*vide* above).

Infested on June 28, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected and moulted into adults in due time; later they were used for the infestation of Cattle 1088 and

1145 in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 25 and 26).

16. Ox 621 was rendered immune by inoculation (*vide* above).

Infested on July 2, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected within the usual time, and moulted into adults on September 19, 1910; the adults were later placed on Cattle 1088 and 1145 to test their infectivity (*vide* Experiment No. 1 "C," Nos. 25 and 26).

17. Heifer 895 was rendered immune by inoculation.

Infested on July 2, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected from July 4 to 14, 1910, and moulted into adults on September 19, 1910; they were later placed on Cattle 1088 and 1145 in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 25 and 26).

18. Heifer 836 was rendered immune by inoculation (*vide* above).

Infested on July 2, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected from July 4 to 14, 1910, and moulted into adults on September 19, 1910; they were later placed on Cattle 1088 and 1145 in order to test their infectivity (*vide* Experiment No. 1 "C," Nos. 25 and 26).

19. Cow 679 was rendered immune by inoculation (*vide* above).

Infested on July 2, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected from July 4 to 14, 1910, and moulted into adults on September 19, 1910. In order to test their infectivity they were placed on Cattle 1088 and 1145 (*vide* Experiment No. 1 "C," Nos. 25 and 26).

20. Bull rendered immune by inoculation (*vide* above).

Infested on July 2, 1910, with brown nymphæ off Cattle 700, 923, and 917 (Ref. Nos. 309, 268, and 335).

Note.—The engorged nymphæ were collected from July 4 to 14, 1910, and moulted into adults on September 19, 1910; later in order to test infectivity they were placed on Cattle 1088 and 1145 (*vide* Experiment No. 1 "C," Nos. 25 and 26).

EXPERIMENT No. 1 (*continued*).

"C." TO SHOW THAT THE TICKS WHICH AS NYMPHÆ HAD COMMUNICATED THE DISEASE TO SUSCEPTIBLE CATTLE (Nos. 596, 561, 908, 919, 914, 1012, 1026, AND 1040), OR WHICH HAD PASSED THEIR NYMPHAL STAGE ON ANIMALS ARTIFICIALLY IMMUNISED Nos. 829, 883, 836, 895, 1047, 1033, 871, 621, 895, 836, 679, AND 615) DO NOT TRANSMIT THE DISEASE IN THEIR ADULT STAGE TO SUSCEPTIBLE CATTLE.

(*f*) RHIPICEPHALUS APPENDICULATUS (Ref. No. 268).

Note.—The following Cattle Nos. 1022, 1060, 1088, 1045, 1057, and 1058 were all born and bred in areas free from East Coast Fever, and accordingly were susceptible to the disease.

21. Heifer 1022 was infested on June 23, 1910, with brown adults off Heifer 923 (Ref. No. 268). This infestation was repeated on June 28th, July 15th, July 20th, July 28th, August 3rd, and August 20th. Altogether 100 ticks were placed on this heifer, but not all of them became attached.

Remarks.—This animal remained quite healthy.

22. Heifer 1060 was infested on August 29, 1910, with brown adults of Heifer 923 (Ref. No. 268), and was re-infested on September 14, 1910; 8 ticks of the first infestation were counted to be fast and 18 of the second lot.

Remarks.—This heifer remained healthy. Later she was used for inoculation purposes, and was finally exposed to East Coast Fever infection on the farm "Burnside," Natal, and died on the 21st day of East Coast Fever (*vide* article on "Progress Report on the Possibility of Vaccinating Cattle against East Coast Fever," Experiment 6 "D").

23. Heifer 1088 was infested on December 15, 1910, with a large number of brown adults which as nymphæ had given the disease to Cattle Nos. 561, 908, 919, 914, 917, 1011, 1012, 1026, 1040, or which as nymphæ had fed on immune Cattle Nos. 1047, 1033, 871, 621, 895, 836, 679, 615, 829, and 883; the ticks were fast on December 16, 1910.

Remarks.—Heifer 1088 did not contract East Coast Fever from this infestation, but was used later for inoculation purposes (*vide* article cited above, Experiment 9 "J"); finally was exposed at "Burnside" and died of East Coast Fever complicated with Redwater.

24. Calf 1145 was infested on January 6, 1911, with large numbers of brown adults off Cattle Nos. 561, 908, 909, 914, 917, 1011, 1012, 1026, 1040, 1047, 1033, 871, 621, 895, 836, 679, 615, 883, and 829.

Remarks.—The calf did not contract East Coast Fever from this infestation, but died from Enteritis on February 14, 1911.

25. Heifer 1057 was infested on August 5, 1910, with large numbers of adults which had passed their nymphal stage on Cattle 829, 883, 836, and 895 (Ref. No. 309); she was re-infested on August 19th and 29th with ticks of the same batch. A good many ticks were found fast the following day. The engorged females dropped on August 13th and 23rd, and September 5th.

Remarks.—Heifer 1057 did not contract East Coast Fever from this infestation. It was used later for inoculation experiments (*vide* article quoted above, Experiment 6 "B").

26. Heifer 1058 was infested on August 5, 1910, with large numbers of brown adults off Cattle 829, 883, 836, and 895 (Ref. No. 309). The ticks were found to be fast the following day, and large numbers of engorged females were collected from August 23rd.

Remarks.—Heifer 1058 did not contract East Coast Fever from this inoculation. It was used later for inoculation experiments (*vide* article cited above, Experiment 6 "K") finally exposed in "Burnside" and died of East Coast Fever. Plasma bodies were found in the blood, spleen, and glands on post-mortem examination.

Results.—None of the six animals which were infected with "cleaned" ticks developed East Coast Fever from the infestation.

Conclusions.

The adult ticks which as larvæ had fed on sick animals, and which as nymphæ had communicated the disease to nine susceptible cattle, or which had been feeding on twelve artificially immunised cattle, did not communicate East Coast Fever when placed in large numbers on six susceptible cattle.

These observations were made on a fair number of animals and with a great many ticks, so that all coincidences can be excluded.

EXPERIMENT No. 2.

TO SHOW THAT TICKS WHICH HAVE BEEN FEEDING ON CATTLE SUFFERING FROM EAST COAST FEVER DO NOT ALWAYS TRANSMIT THE DISEASE IN THEIR SUBSEQUENT STAGE.

Particulars of the Ticks used.

I.

Rhipicephalus appendiculatus (Ref. No. 319).

The larvæ originated from mothers collected in Natal on March 18, 1910; the eggs were laid in the laboratory on March 25th and the larvæ

hatched out on April 26, 1910. The larvæ were placed on Heifer 1013 on the 7th day of the fever reaction (May 30, 1910), and were collected during the three days previous to death, which occurred from East Coast Fever on June 7, 1910; during the time the ticks were feeding on Heifer 1013 the parasites of East Coast Fever were frequently met with, and all stages of development were found in the lymphatic glands.

The larvæ moulted into nymphæ on August 5, 1910.

II.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 364).

The larvæ originated from mothers collected in Natal on March 18, 1910; the eggs were laid at the laboratory on March 25th, and the larvæ hatched out on April 26, 1910. The larvæ were placed on Heifer 908 on August 12, 1910, viz., the 5th day after the rise of temperature, and were collected 5 days before death, which occurred on August 22, 1910, during which period the blood showed *Theileria parva* in large numbers, and in the spleen and glands plasma bodies were very frequently met with.

The larvæ moulted into nymphæ on September 10, 1910.

III.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 355).

The larvæ originated from mothers collected in Natal on March 18, 1910, and the eggs were laid in the laboratory on March 25; the larvæ hatched out on April 26, 1910. The larvæ were placed on Heifer 913 on July 14, 1910, at a time when the parasites of East Coast Fever were frequently met with, and the engorged larvæ were collected from July 19 to 21, 1910. Heifer 913 was killed on July 22, 1910. The examination of the blood since July 14th had shown the presence of the East Coast Fever parasites in but rare numbers; free plasma bodies (agamogonous forms) had been noted in the glands.

The larvæ moulted into nymphæ on September 1, 1910.

IV.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 356).

The larvæ originated from mothers collected in Natal on March 12, 1910. The eggs were laid at the laboratory on March 25th, and the larvæ emerged on April 18, 1910. The larvæ were placed on Heifer 914 on July 14, 1910, and were collected from July 17th to 20th. On July 18th *Th. parva* were noted in the blood of Heifer 914, and plasma bodies were seen in the glands. The heifer recovered.

The engorged larvæ moulted into nymphæ on September 15, 1910.

V.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 349).

The engorged nymphæ were collected off sick cattle in Natal on June 29, 1910, and moulted in the laboratory on September 11, 1910.

VI.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 411).

The larvæ originated from mothers collected in Natal on March 12, 1910. The eggs were laid at the laboratory on March 14, 1910, and the larvæ hatched on April 18, 1910. The larvæ were placed on Heifer 914, suffering from East Coast Fever, on July 14, 1910. The engorged larvæ were collected from July 17th to 20th and moulted into nymphæ on August 15, 1910; they were placed on Heifer 1053 on October 18, 1910, at a time when this heifer was suffering from East Coast Fever and when *Th. parva* were noted in the blood and plasma bodies were seen in the glands. The engorged nymphæ dropped from October 22 to 27, 1910, and moulted into adults on November 21, 1910.

Note.—These ticks had been feeding in both their larval and nymphal stages on animals suffering from East Coast Fever.

VII.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 426).

The larvæ originated from mothers collected in Natal on February 18, 1910, and hatched by March 30, 1910; the larvæ were reared on "clean" Heifer 868 and dropped from July 12 to 15, 1910; they moulted on August 23, 1910, and the nymphæ were placed on Heifer 1111 on October 26th at a time when this heifer was suffering from East Coast Fever. *Th. parva* being found in the blood and plasma bodies in the glands. The engorged nymphæ dropped from October 31 to November 5, 1910, and moulted into adults on November 26, 1910.

VIII.

RHIPICEPHALUS APPENDICULATUS (Ref. No. 373).

The adult females originated from Cattle 906, 1088, 1009, and 1021, animals which were kept at the laboratory. The eggs hatched on November 18, 1910, and the larvæ were placed on Heifer 909 on January 2, 1911, at a time when this heifer was undergoing an attack of East Coast Fever and when *Th. parva* and plasma bodies were noted in the blood and glands respectively.

The engorged larvæ were collected from January 5 to 7, 1911, and moulted about January 20, 1911, into nymphæ.

Testing of the Ticks.

(*a*) BROWN NYMPHÆ (Ref. Nos. 363, 364, 355, 356, and 349).

1. Heifer 627 had previously been used for inoculation experiments in connection with the transmission of East Coast Fever, but with negative results.

Infested with brown nymphæ (Ref. No. 363), on August 17, 1910; about 20 were found attached the following day, and the engorged nymphæ were collected on August 23rd. No reaction ensued.

Re-infested on September 15, 1910, with 20 brown nymphæ (Ref. No. 364). All 20 ticks were found attached on the following day. No reaction followed.

Re-infested on September 30, 1910, with brown nymphæ (Ref. Nos. 355 and 356). On the following day 14 ticks were found attached. No reaction ensued.

Re-infested on October 20th with 6 brown adults, originating from Natal (Ref. No. 349). These adults were found fast on October 21st. The heifer contracted East Coast Fever and died on November 27, 1910.

2. Heifer 911 had been previously used for inoculation purposes in connection with the artificial transmission of East Coast Fever, but with negative results.

Infested on August 17th with a number of brown nymphæ (Ref. No. 319). About 70 ticks were found fast the following day, and the engorged nymphæ were collected on August 23rd. No reaction followed.

Re-infested on September 15th with brown nymphæ (Ref. No. 364). 20 ticks were found attached the following day. No reaction ensued.

Re-infested on September 30, 1910, with brown nymphæ (Ref. Nos. 355 and 356). On October 1st, 20 ticks were found fast. No reaction ensued.

Re-infested on October 20, 1910, by the infestation of 6 brown adults, origin Natal (Ref. No. 349). The heifer contracted East Coast Fever and died on November 6, 1910.

3. Heifer 1014 had been previously used in connection with the artificial transmission of East Coast Fever, but with negative results.

Infested on August 17, 1910, with brown nymphæ (Ref. No. 319). 24 ticks were found fast the following day, and the engorged nymphæ dropped on August 23, 1910. No reaction resulted.

Re-infested on September 15, 1910, with 20 brown nymphæ (Ref. No. 364). 20 ticks were fast on September 16, 1910. No reaction ensued.

Re-infested on September 30, 1910, with brown nymphæ (Ref. Nos. 355 and 356. 10 ticks were found fast the following day. No reaction followed.

Re-infested on October 20, 1910, by the infestation of 6 brown adults, origin Natal (Ref. No. 349). Heifer 1014 contracted East Coast Fever and died on November 21, 1910.

4. Cow 1068 had been previously used in connection with the artificial transmission of East Coast Fever, with negative results.

Infested on August 17, 1910, with brown nymphæ (Ref. No. 363). On the following day about 70 were found fast. The engorged nymphæ were collected on August 23, 1910. No reaction ensued.

Re-infested on September 15, 1910, with brown nymphæ (Ref. No. 364). 20 ticks were found attached the following day. No reaction resulted.

Re-infested on September 30, 1910, with brown nymphæ (Ref. Nos. 355 and 356). 14 ticks were fast the next day. No reaction.

Re-infested on October 20, 1910, with 6 brown adults, origin Natal (Ref. No. 349). 5 adults were fast the next day. This cow contracted East Coast Fever and died on November 21, 1910.

(*b*) Brown nymphæ (Ref. Nos. 363 and 373).

5. Ox 1037 had been previously used for the artificial transmission of East Coast Fever, but with negative results.

Infested on September 5, 1910, with brown nymphæ (Ref. No. 319). 27 ticks were found to be attached the following day. No reaction ensued.

Re-infested on January 30, 1911, with 20 brown nymphæ off Heifer 909 (Ref. No. 373). 20 ticks were found fast the following day. Ox 1037 contracted East Coast Fever and died on February 22, 1911.

(*c*) Brown nymphæ (Ref. Nos. 363, 364, and 349).

6. Ox 1046 had been previously used for the artificial transmission of East Coast Fever, but with negative results.

Infested on September 5, 1910, with brown nymphæ (Ref. No. 319). 28 ticks were found attached the following day. No reaction developed.

Re-infested on October 20, 1910, with 10 brown nymphæ (Ref. No. 364). On the following day 8 ticks were found fast. No reaction followed.

Re-infested on November 16, 1910, with 4 brown adults, origin Natal (Ref. No. 349). 3 adults were fast the following day. No reaction ensued.

Re-infested on December 8, 1910, with 6 brown adults off East Coast Fever animal 1053 (Ref. No. 411), and re-infested six days later with 2 brown adults off 1053 (Ref. No. 411) and 2 brown adults off Heifer 1111 (Ref. No. 426). 4 ticks of the first batch and 1 tick of the second batch were found fast on the day after infestation Ox 1046 contracted East Coast Fever and died on January 8, 1911.

(*d*) BROWN NYMPHÆ (Ref. Nos. 363 and 364).

7. Ox 1043 had been previously used for the artificial transmission of East Coast Fever, with negative results.

Infested on September 5, 1910, with brown nymphæ (Ref. No. 319). 33 ticks were found attached the following day. No reaction resulted.

Re-infested on October 20, 1910, with 10 brown nymphæ (Ref. No. 364). 6 nymphæ were fast the following day. Ox 1043 contracted East Coast Fever and died on November 18, 1910.

8. Heifer 1017 had been previously used in connection with the artificial transmission of East Coast Fever, but with negative results.

Infested on September 5, 1910, with brown nymphæ (Ref. No. 363). 42 ticks were found attached the next day. No reaction ensued.

Re-infested on October 20, 1910, with 10 brown nymphæ (Ref. No. 334). All 10 ticks were fast the following day. A fever reaction set in and Heifer 1017 died of East Coast Fever on November 9, 1910.

(*e*) RHIPICEPHALUS APPENDICULATUS (Ref. Nos. 364, 349, 411, and 426).

9. Heifer 1090 had not been used previously in any experiment, and was purchased in an area free from East Coast Fever.

Infested on October 20, 1910, with 10 brown nymphæ (Ref. No. 364). On the following day 6 nymphæ were found fast, but no reaction developed.

Re-infested on November 16, 1910, with 4 brown adults (Ref. No. 349), origin Natal. 2 adults were fast the following day, but no reaction ensued.

Re-infested on December 8, 1910, with 6 brown adults off Heifer 1053 (Ref. No. 411). 5 ticks were attached the following day.

Re-infested on December 14th with 2 brown adults off Heifer 1053 (Ref. No. 411) and 2 adults off 1111 (Ref. No. 426). 2 adults were fast the following day. A reaction set in, and the animal died of East Coast Fever on December 27, 1910.

(*f*) RHIPICEPHALUS APPENDICULATUS (Ref. Nos. 363, 364, and 349).

10. Heifer 1082, an animal which had been born in an area free from East Coast Fever and had not been used previously.

Infested on August 30, 1910, with brown nymphæ (Ref. No. 319). 23 ticks were found attached on September 6, 1910, but no reaction followed.

Re-infested on September 15, 1910, with 20 brown nymphæ (Ref. No. 364). No reaction followed.

Re-infested on October 20, 1910, with 6 brown adults, origin Natal (Ref. No. 349). On the following day 5 adult ticks were found fast. A reaction set in, and the animal died of East Coast Fever on November 25, 1910.

(*g*) RHIPICEPHALUS APPENDICULATUS, nymphæ (Ref. No. 364).

11. Ox 1050 had been previously used in connection with the artificial transmission of East Coast Fever, without results.

Infested on October 20, 1910, with 10 brown nymphæ (Ref. No. 364). 7 ticks were found attached the following day. A reaction set in, and the ox died on November 21, 1910, of East Coast Fever.

Results.

RHIPICEPHALUS APPENDICULATUS, nymphæ (Ref. No. 319).

These ticks failed to transmit the disease in every instance, and the 9 animals which were infested were proved subsequently to be susceptible to East Coast Fever. The larvæ hatched out on April 26, 1910, and became infected at the end of May and beginning of June, that is, about 5 to 6 weeks after they had hatched. They moulted into nymphæ on August 5th, viz., about 2 months after they had become replete on Heifer 1013. The shortest moulting period in this stage is 16 days in the summer. They were placed on the susceptible animals as follows:—

Heifer	627	infested on August 17, 1910	20	ticks were fast
	911	,, ,, ...	70	,,
	1014	,, ,, ...	24	,,
	1068	,, ,, ...	70	,,
	1082	,, August 30, 1910	20	,,
	1037	,, September 5, 1910	27	,,
	1046	,, ,, ...	28	,,
	1017	,, ,, ...	42	,,
	1043	,, ,, ...	33	,,

That is to say, 12 days, 25 days, and one month after they had moulted.

RHIPICEPHALUS APPENDICULATUS, nymphæ (Ref. No. 364).

These ticks failed to transmit the disease in seven instances out of ten, the three positive cases being Cattle Nos. 1043, 1017, and 1050. These ticks hatched on April 26, 1910 (the same as batch No. 363, belonging to the same original lot), and were placed on Heifer 908 on August 12th, namely, about 107 days after they had hatched. They moulted into nymphæ on September 10, 1910.

They were placed on the following animals:—

Heifer	627	on September 15, 1910, and	20	became attached
	911	,, ,,	20	,,
	1068	,, ,,	20	,,
	1050 (died)	,, ,,	7	,,
	1082	,, ,,	20	,,
	1014	,, ,,	20	,,
	1046	on October 20, 1910	8	,,
	1043 (died)	,,	6	,,
	1090	,,	6	,,
	1017 (died)	,,	10	,,

Of the animals infested on September 15th one died, and of the animals on October 20th two died. It is remarkable that in this instance the minimum number of ticks (6 and 10) transmitted the disease.

RHIPICEPHALUS APPENDICULATUS, nymphæ (Ref. Nos. 355 and 356).

These ticks failed to transmit the disease in four instances when used together for the purposes of infestation.

The larvæ of batch 355 hatched on April 26, 1910, and when they were 79 days old were infected with East Coast Fever; they moulted into nymphæ on September 1, 1910.

Larval ticks number 356 hatched on April 18, 1910, and when 95 days old were infected with East Coast Fever; they moulted into nymphæ on August 15, 1910.

They were placed on the following cattle:—

	627	on September 30, 1910, and	14	became attached
	911	,, ,,	20	,,
	1014	,, ,,	10	,,
	1068	,, ,,	14	,,

RHIPICEPHALUS APPENDICULATUS, adults (Ref. No. 349).

These ticks transmitted the disease to five animals out of seven. The engorged nymphæ were collected off sick cattle in Natal on June 29, 1910, and moulted into adults at the laboratory on September 11, 1910, or 74 days after collection.

They were used for the infestation of—

Cattle	627	on October 20, 1910	3	became attached
	911	,, ,, ...	6	,,
	1014	,, ,, ...	6	,,
	1068	,, ,, ...	5	,,
	1082	,, ,, ...	5	,,
	1046	,, ,, ...	3	,,
	1090	on November 16, 1910	2	,,

RHIPICEPHALUS APPENDICULATUS, nymphæ (Ref. No. 373).

These ticks transmitted the disease to one animal (1037). As larvæ they were infected on Heifer 909 on January 7, 1910. They moulted into nymphæ on January 20, 1911, and were used on January 30, 1911, when 10 days old.

They were placed on—

Heifer 1037 on January 30, 1911, and 20 became attached.

RHIPICEPHALUS APPENDICULATUS, adults (Ref. Nos. 426 and 411).

Batch No. 426 transmitted the disease to two animals, 1040 and 1090. They were infected as nymphæ on October 26, 1910, and moulted into adults on November 26, 1910.

Batch No. 411 were infected as nymphæ on October 18, 1910. They moulted into adults on November 21, 1910.

The adults of batch 426 were 18 days old when used, and the adults of batch 411 were 18 days old when used.

Ticks Ref. No. 411 were placed on Heifer 1046 on December 8, 1910, of which 4 became attached, and on December 14th Ref. Nos. 411 and 426 were infested, of which 1 became attached. Ref. No. 411 undoubtedly transmitted the disease. Ref. No. 411 were also placed on Heifer 1090 on December 8, 1910, of which 5 became fast, and on December 14, 1910, 411 and 426 were infected, of which 2 became fast. The last batch transmitted the disease.

EXPERIMENT No. 3.

TO NOTE WHETHER BROWN ADULTS WHICH WERE FEEDING AS LARVÆ ON CATTLE SUFFERING FROM EAST COAST FEVER, AND WHICH PROVED TO BE VIRULENT AS NYMPHÆ, WILL TRANSMIT THE DISEASE TO ADULTS AFTER HAVING PASSED THEIR NYMPHAL STAGE ON A RABBIT.

Particulars of the Ticks.

1. RHIPICEPHALUS APPENDICULATUS (Ref. No. 342).

The larvæ originated from mothers collected in Natal on January 12, 1910; the eggs were laid on January 18th, and the larvæ hatched on February 18, 1910, and were placed on 923 on March 20, 1910 (Ref. No. 268), at a time when the parasites of East Coast Fever were frequently noted in the blood. The engorged larvæ were collected on March 23, 1910, and hatched out in due time. One lot was placed on Cow 596 on April 7, 1910, and transmitted the disease (*vide* Experiment No. 1 (*a*)). A second lot was placed on a rabbit, and the engorged nymphæ were collected from April 13 to 29, 1910.

2. RHIPICEPHALUS APPENDICULATUS (Ref. No. 309).

The larvæ originated from mothers collected in Natal; the eggs were laid on December 24th and the larvæ hatched on January 30, 1910; they were placed on Calf 700 on February 27, 1910 (*vide* Experiment No. 1 (*b*)). The engorged larvæ were collected during the period when the parasites of East Coast Fever were frequently met with in the blood. These engorged larvæ hatched on March 17, 1910, and the nymphæ were placed on Calf 917 (*vide* Experiment No. 1 (*c*)), and transmitted the disease. Another lot was placed on rabbits, and the engorged nymphæ were collected from June 3 to 7, 1910. They moulted on May 4, 1910.

Testing the Ticks.

1. Heifer 1059 was infested on August 29, 1910, with adult brown ticks (Ref. No. 342) of the first rabbit. A re-infestation was made on September 14th with ticks of the second rabbit (Ref. No. 309). On September 19, 1910, 26 ticks were found attached. No reaction followed; the heifer eventually died of East Coast Fever at "Burnside."

2. Heifer 1019 was infested on June 23rd with 20 brown adults of the first rabbit (Ref. No. 342). On June 28th it was re-infested with 20 brown adults of the second rabbit (Ref. No. 309). On the following day 8 adults were found attached. On July 15th and 20th and on August 3rd and 20th this heifer was re-infested with brown adults of the first rabbit

(Ref. No. 342). On July 28th 9 ticks were found fast. On August 4th no ticks could be seen. No reaction followed, but the animal eventually died at "Burnside" of East Coast Fever.

CONCLUSION.

The infestation of two susceptible heifers with adult brown ticks which in their larval stage had been feeding on cattle suffering from East Coast Fever (and as nymphæ proved infective for cattle) did not convey East Coast Fever as adults after they had passed their nymphal stage on a rabbit.

EXPERIMENT No. 4.

TO NOTE WHETHER BROWN ADULTS WHICH FED AS NYMPHÆ ON CATTLE IMMUNE TO EAST COAST FEVER WILL TRANSMIT THE DISEASE TO SUSCEPTIBLE CATTLE.

Particulars of Ticks.

Heifer 914 had been infested with brown nymphæ (Ref. Nos. 268, 335, and 309) on June 28, 1910, and contracted East Coast Fever, from which it recovered. Plasma bodies were found in the glands and *Theileria parva* in the blood. The heifer showed a typical East Coast Fever reaction, and by the end of May had completely recovered.

History of Ticks used to Infest the Immune Heifer.

Brown nymphæ (Ref. No. 298) off Heifer 868, susceptible to East Coast Fever, were placed on Heifer 914 on September 2, 1910. These nymphæ engorged and dropped on September 6 and 7, 1910.

Testing the Ticks.

They moulted into adults on October 19, 1910, and on December 15th these adult ticks were placed on Heifer 1021. The following day the ticks were found fast. No reaction followed. Heifer Calf 1130 was infested on January 6th with ticks of the same batch as above (brown adults, Ref. No. 298), and the following day they were found attached. No reaction followed.

CONCLUSION.

The infestation of two susceptible cattle with adult brown ticks which had passed their nymphal stage on a heifer immune to East Coast Fever did not convey the disease. This observation supports some conclusions made as far back as 1903.

SUMMARY OF CONCLUSIONS.

In the foregoing experiments it has been proved—

1. That brown tick imagines which as larvæ had become infected with East Coast Fever and which had transmitted the disease in their nymphal stage were no longer infective for susceptible cattle. Four batches of ticks proved their infectivity in the nymphal stage on eight animals, but in their adult stage failed to transmit the disease to two susceptible animals.

2. Ticks belonging to the same batches which were feeding on two animals rendered immune to East Coast Fever by inoculation in the nymphal stage did not transmit the disease in their adult stage to six animals, thus proving that the brown tick which has become infected in one stage cleans itself in the following stage by feeding on an immune or susceptible animal.

3. Ticks which became infected with East Coast Fever in their larval stage, and which passed their nymphal stage on a rabbit, did not prove to be infective in their adult stage for susceptible cattle. This conclusion bears out that given above (2), showing that a tick loses its infectivity the first time it feeds on an animal susceptible or immune to East Coast Fever.

4. Clean or infective ticks feeding on an animal which has recovered from an attack of East Coast Fever do not transmit the disease in their next stage. This conclusion is in support of experiments undertaken eight years ago (*vide* Annual Report of the Government Veterinary Bacteriologist, 1904–05).

5. It has been demonstrated that certain batches of ticks collected at the same time and which fed under similar conditions do not transmit the disease in their next stage, even when infested in great numbers and on numerous animals. Other batches of ticks reared in exactly the same way and under similar conditions only infected a few animals, whilst again other tricks proved infective in almost every instance even when a minimum number were used.

It is difficult to give an explanation of this fact, but it is quite likely that outside conditions have some influence. The ticks which did not transmit the disease were bred during the coldest time of the year. This may perhaps explain the fact that during the winter months the infection in the field is not so active as during the summer months, remembering at the same time that during the winter months tick life is generally weaker than in the summer.

THE SPECTRUM OF THE RUBY—PART III.

By James Moir, M.A., D.Sc., F.C.S., F.R.S.S.Af.

(Read October 18, 1911.)

1. In addition to the series of eight thin spectrum lines described in Part II., two additional faint bands have been discovered by employing a very deeply coloured artificial ruby and concentrated sunlight. Both lie in the extreme red beyond the transmission line, and their approximate wave-lengths are 7000 and 7150.

2. By dissolving an artificial ruby in fused bisulphate, precipitating with ammonia, boiling till neutral, and fusing the precipitate (after washing and drying) with soda and nitre, the author has succeeded in demonstrating the presence of chromium as the element causing the colour. The cause of the spectrum, however, still remains unsettled.

3. The remarkable observation was made that the ruby, when heated to a temperature below a red heat, changes colour, through brown to green. Whilst hot the spectrum is that of ordinary chromium—without any of the special ruby lines. On cooling it slowly recovers its original colour and spectrum. This process was followed more closely by spectroscoping a ruby immersed in a bath of hot spermaceti, and illuminated at the focus of a lens. Even at the low temperature of 250° C. the red transmission band became faint and ill-defined. This and the two strong violet lines all disappeared at 290–300°, although faint signs of the two absorption bands bordering the red transmission could be seen up to 340°. In addition, the whole absorption of the stone shifts towards the red, the violet end shifting up to F as in the ordinary chromium spectrum. Even at 180° the stone is distinctly redder (less rose-coloured) than when cold. Plattner's book on the blowpipe describes a similar change of colour due to chromium in pyrope and spinel, which, however, have no definite spectrum, and are isotropic.

4. By means of a specially improvised arrangement an examination of a corundum plate under the combined action of a red heat and of polarised

light was successfully accomplished. The plate was attached to an iron lid, which could be rotated while a Bunsen burner was playing on it. The effect of heat on the birefringence of corundum was found to be exceedingly small—in fact, such as might be caused by the mere expansion of the mineral. The spectrum of the ruby depends, therefore, on the chromium, and not on the crystalline structure of the alumina; in fact, apparently the only possible explanation left is the nature of the chromium atom itself.

The author wishes to acknowledge the most valuable help and suggestions given by Mr. Max Weber, curator of the Johannesburg Museum, in this work.

SOME CAUSES AND EFFECTS OF VARIATION IN THE RANGE OF TEMPERATURE.

By J. R. Sutton, Sc.D., F.R.S.S.Af., Hon. Memb. R.Met.S., and Elizabeth M. Sutton, F.R.Met.S.

(Read October 18, 1911.)

The present joint paper contains the results of a discussion of some of the more salient meteorological aspects of a variation in the range of air temperature. The investigation was instituted with the primary object of determining what variation, if any, of the diurnal curve of barometric pressure might accompany a greater or less range of temperature as night followed day; but other points had necessarily to be considered so that we might be able to assign as nearly as possible the position of the range curve in the sequence of meteorological cause and effect. We have, however, adhered to our original intention of making the range of temperature the basis of the argument.

The meteorological elements taken into account here are the monthly means of:—

1. The diurnal range of air temperature;
2. The maximum temperature of the air;
3. The minimum temperature of the air;
4. The hourly mean temperature of the day;
5. The range of dew-point temperature from VIII. to XIV.;
6. The hourly mean dew-point temperature;
7. The range of relative humidity from VIII. to XIV.;
8. The hourly mean relative humidity;
9. The range of barometric pressure from VIII. to XIV.;
10. The hourly mean pressure;
11. The mean percentage of sunshine;
12. The mean percentage of cloud derived mainly from six observations a day;
13. The mean rainfall;
14. The total rainfall in the period studied.

For each given month the month's mean values of each of these elements are arranged according to the magnitude of the range of temperature in any year 1897 to 1910, some months of 1911 having been included. The method of arrangement will be followed in Table 1, showing the results for one month, *i.e.*, July, of which it is perhaps only necessary to say that the *minus* sign in the dew-point column indicates that the vapour pressure is less at VIII. o'clock than it is at XIV.; the *plus* sign when it occurs—in other months—that the vapour pressure is greater at XIV.

Table 2 gives for the year corresponding information to that which Table 1 gives for the month; the "A" line, of the year, containing for each column the averages of the "A" lines of each month; and so on for the "B," "C," "D," ... lines. The numbers in each column of Table 2 have, however, first of all been smoothed in threes by Bloxam's method.

Table 2 would seem to be of peculiar interest. With one exception all the elements in question respond to the rise and fall of the range of temperature curve. The following *increase* more or less regularly as the mean monthly range of temperature increases:—

2. The maximum temperature;
4. The mean temperature;
9. The range of pressure;
11. The duration of sunshine.

The following *decrease* more or less regularly as the range of temperature increases:—

3. The minimum temperature;
5. The range of the dew-point;
6. The mean dew-point;
7. The range of relative humidity;
8. The mean humidity;
12. The cloudiness of the sky;
13. The mean rainfall;
14. The number of rainy days in a month.

The one exception is the mean pressure of the month, which commences by falling, but concludes by rising as the range of temperature increases in magnitude. Whether this anomalous behaviour of the

monthly value of mean pressure arises physically or fortuitously is not yet clear.

The general tendency of some of the results given in Table 2 is perhaps what would have been expected. Thus, *e.g.*, we should expect that the greater cloudiness of the sky, the heavier rainfall, and the greater number of rainy days in any given month would go with a diminished percentage of sunshine. It is not so obvious, however, that these should also go with a uniform decrease of both maximum and mean temperature and an increase of both minimum temperature and range of temperature, especially when it is remembered that some of the hottest Kimberley summer days are to a greater or less extent characterised by clouded skies. Nor does it necessarily follow, as a mere piece of intellectual reasoning, that the range of dew-point temperature, or the range of relative humidity, should increase as the range of temperature decreases. In any case, whether the results are, or are not, much as might be expected, the actual measures are of interest. In particular, the mutual relationship of sunshine and cloud is worth attention. It will be seen that the sum of the percentages of sunshine and of cloud is not a constant quantity, but that it becomes greater as the range of temperature becomes less, rising from a total of 106 per cent. when the range of temperature is 32°·6 to a total of 114 per cent. when the range of temperature is 24°·3.

The minimum temperature does not rise at the same rate as the maximum temperature falls in the interval between the average month's greatest range of temperature to its least. Thus it comes about that the average month of least range of temperature is also the average month of least mean temperature. This is important. Professor Haughton's lectures have been quoted as teaching that the mildness of the climate of the West of Ireland is due to the abundant rainfall. It has been suggested that this mildness of temperature is a direct consequence of the heat disengaged in the process of condensation from aqueous vapour to rain. The suggestion does not hold water. The Kimberley results show that although the nights are a little warmer in the wet months the days are colder by a greater number of degrees. That is to say, whatever the "blanketing" action of the clouds may be, or whatever the quantity of heat disengaged in the process of condensation, the radiation that is checked by, and the latent heat that is received from the clouds, are together less than the direct solar heat that is shut off by the clouds from the earth's surface.

During the winter months the diurnal curve of dew-point temperature is quite unlike what it is in the summer. In the winter half-year, April to September, the vapour tension is higher at XIV. than it is at VIII., whereas for the rest of the year the case is the other way about. A sepa-

ration of the winter and summer parts of column (5) of Table 2 gives us the following result :—

RANGE OF MONTHLY DEW-POINT TEMPERATURE COMPARED WITH MONTHLY RANGE OF TEMPERATURE.

	Winter.	Summer.
	°	°
A	−3·4	+1·9
B	3·3	2·1
C	3·1	2·2
D	3·1	2·3
E	2·8	2·7
F	2·8	3·0
G	2·6	2·8
H	2·6	2·8
I	2·5	2·7
J	2·5	2·8
K	2·2	2·7
L	1·7	2·5
M	1·5	2·4
N	1·6	2·2

giving the curious result that in the winter half-year the diurnal variation in the total moisture content of the lower air diminishes as the air becomes damper, whereas in the summer half-year the corresponding variation is less both when the sky is very clear and when it is very cloudy—an intermediate state of things with regard to the sky (and of course with regard to the range of temperature) giving the greatest range of dew-point from VIII. to XIV. o'clock. Summer and winter taken together obliterate this purely summer effect. The relative humidity has no similar analogue.

The only other question discussed in this paper is the effect of a variation in the range of temperature upon the harmonic constants in the diurnal curves of temperature and barometric pressure.

For any given month arranged as in Table 1, the first five lines A—E, and the last five J—N, are taken, and the mean diurnal curves of temperature and barometric pressure of each for the given month for the years which happen to fall in these respective two sets are computed. Thus, for example, the mean diurnal curves of temperature and barometric pressure for July for the years 1898, 1902, 1901, 1897, and 1906 are computed for the greater range of temperature (which here averages 32°·5); and the same two elements for the same month for the years 1909, 1910, 1908, 1900, and 1899, are computed for the lesser range of temperature (which here averages 27°·0).

The constants of the first three harmonic terms in the diurnal curves of barometric pressure (deduced as above) for the greater, and for the less, ranges of temperature are set forth in Tables 3 and 4 respectively. It appears from these Tables that a difference in the monthly mean range of temperature makes no material difference in the phase times of either the 24-hour wave (V_1), the 12-hour wave (V_2), or the 8-hour wave (V_3). The amplitudes (u_1, u_2, u_3) are nevertheless more or less dependent upon the range of temperature, besides depending—the first and third in particular—upon the time of year.

The following are the ratios, $u\alpha/u\beta$, of the amplitudes pertaining to the greater range of temperature to those pertaining to the lesser range :—

	$\frac{M-m}{\alpha-\beta}$	$\frac{u_1}{\alpha/\beta}$	$\frac{u_2}{\alpha/\beta}$	$\frac{u_3}{\alpha/\beta}$
	°			
Jan.	6·1	1·224	·996	1·000
Feb.	6·1	1·273	1·142	1·909
Mar.	5·4	1·132	1·055	·923
April	6·5	1·075	·967	·976
May	7·5	1·263	·988	1·315
June	3·7	1·177	·958	1·074
July	5·5	1·135	1·041	1·071
Aug.	3·1	1·153	·983	1·196
Sept.	5·5	1·189	1·024	0·794
Oct.	4·4	1·074	1·047	10·000
Nov.	3·9	1·051	1·063	1·611
Dec.	3·1	1·022	·941	1·471
Year	5·1	1·139	1·015	1·162

Judging by Tables 3 and 4 the direct dependence of the second and third harmonic terms upon the range of temperature must be slight at the best. On account of its regularity the ratio α/β given above is much more satisfactory for the first harmonic term than it is for the other two. Averages for all the months in which $\alpha-\beta$ exceeds its mean value ($=5°{\cdot}1$) or falls short of it are :—

No. of Cases.	$\frac{M-m}{\alpha-\beta}$	$\frac{u_1}{\alpha/\beta}$	$\frac{u_2}{\alpha/\beta}$
	°		
7	6·2	1·184	1·030
5	3·8	1·095	·998

It appears from this that the greater the difference between the ranges of temperature for any month given in Tables 3 and 4, then the greater the ratio of α to β on the whole for both of the first two harmonic terms. No great faith can be placed upon the result for the second harmonic term, though. At the same time the ratio is suggestive, and should it be confirmed by a longer series of observations, we should have to conclude that some portion of the second harmonic term of pressure is of local origin.

The phase times of the harmonic terms of temperature, given in Tables 5 and 6, are also practically unaffected whether the range of temperature be greater or less. The amplitudes, however, are rather more modified, than those of pressure. The following are the α/β ratios :—

	$\frac{M-m}{\alpha-\beta}$	$\frac{u_1}{\alpha/\beta}$	$\frac{u_2}{\alpha/\beta}$	$\frac{u_3}{\alpha/\beta}$
	°			
Jan.	6·1	1·295	1·246	1·431
Feb.	6·1	1·261	1·305	1·322
Mar.	5·4	1·270	1·196	1·525
April	6·5	1·333	1·197	1·961
May	7·5	1·409	1·386	1·856
June	3·7	1·149	1·063	1·611
July	5·5	1·269	1·171	1·004
Aug.	3·1	1·134	1·126	1·257
Sept.	5·5	1·218	1·271	1·400
Oct.	4·4	1·198	1·195	1·171
Nov.	3·9	1·160	·982	1·597
Dec.	3·1	1·143	1·112	1·118
Year	5·1	1·230	1·184	1·386

The ratios evidently depend fairly closely upon the value of α—β, the first term more so than the other two do. A summary is :—

No. of Cases.	$\frac{M-m}{\alpha-\beta}$	$\frac{u_1}{\alpha/\beta}$	$\frac{u_2}{\alpha/\beta}$	$\frac{u_3}{\alpha/\beta}$
	°			
7	6·2	1·294	1·253	1·500
5	3·8	1·157	1·096	1·351

That is to say, the ratios of the amplitudes are greater when $\alpha-\beta$ is greater.

The amplitudes u_1, in Tables 5 and 6, may be approximately represented by the formula—

$$u_1 = \cdot 42(M-m).$$

From some points of view the harmonic constants look better when computed for the "temperature variability," *i.e.*, for the curve of change of temperature from hour to hour, than they do when they are computed for the hourly temperatures. The harmonic constants in the diurnal curves of temperature variability, or, if we prefer to call it so, in the $\Delta\theta/\Delta t$ curve—where θ is the temperature and t the time counted from midnight—are given in Tables 7 and 8. The angles V_1, V_2, V_3, in this case of course differ by $\pi/2$ from those of Tables 5 and 6. The ratios of the amplitudes of temperature variability to those of temperature, for both greater and lesser ranges of temperature, are approximately—

$$u_1 = 3{\cdot}8;\ u_2 = 1{\cdot}9;\ u_3 = 1{\cdot}3.$$

The respective ratios of the amplitudes of temperature variability for the greater ranges of temperature (α) to the amplitudes for the lesser ranges (β) are the same as those of temperature.

One advantage of working out the harmonic constants for the variability is that they bring into strong relief the fact that the phase times of the three principal waves, given in Tables 7 and 8, group themselves closely about the phase-time of the 12-hour wave of pressure. In fact, all three of the variability component waves come to a maximum within about an hour or less of the time of a maximum of the pressure wave in question. This near coincidence of phase times in the first place, next the tendency which the phase times of the first and second harmonic components of temperature variability as well as the second component of barometric pressure show to come earlier in the day during the spring and early summer months; thirdly, the greater magnitude of the amplitude of the variability curve as well as of the second harmonic component of pressure at the same period; these go to support the idea that the 12-hour pressure wave arises initially as the result of the variation of temperature from instant to instant, and not as a result of temperature alone. Obviously the mere expansion of the air upwards could have no effect upon the pressure beneath, excepting by virtue of the reaction downwards, and this last must be greatest when the upward acceleration of the air is a maximum, *i.e.*, when $d\theta/dt$ is a maximum.*

* See a remarkable paper by Halm published in the *Journal* of the Scottish Meteorological Society, Third Series, No. XXII., 1906. Also Sutton, "The Diurnal Variation of Barometric Pressure," *Report* S.A.A.A.S., 1906. Hann has yet another able paper, "Ueber die Zerlegung des komplexen taeglichen Ganges der Temperatur und des Luftdruckes in eine ganz- und eine halbtaegige Welle," in *Met. Zeit.*, July, 1911.

Tables 9 and 10 give the hourly mean barometric pressures at 32° F. They are obtained from the records of the photobarograph, and have been reduced to agree with the control readings of the Observatory Standard Barometer. Table 9 contains the mean results for the greater ranges of temperature (α), and Table 10 those for the lesser ranges (β).

Tables 11, 12, give the hourly mean temperatures for the greater (α) and lesser (β) ranges of temperature respectively.

TABLE 1.—Comparison of Meteorological Elements (Month).

TABLE 1.—Comparison of Meteorological Elements (Month).

July.		Air Temperature.				Temperature of the Dew-point.		Relative Humidity.		Pressure.		Sun-shine.	Cloud.	Rainfall.	
	Year.	Range.	Maximum.	Minimum.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.	Mean.	Mean.	Total.	Total.
		°	°	°	°	°	°	%	%	Inch.	Inch.	%	%	Inch.	Days.
A	1898	32·9	65·6	32·7	47·4	−7·1	28·4	29·2	50·1	·074	26·266	92	6	·055	1
B	1902	32·8	68·4	35·6	50·1	−4·4	33·2	36·4	55·5	·072	·238	87	17	·125	1
C	1901	32·6	65·8	33·2	47·7	−6·6	29·8	32·4	52·6	·070	·267	89	9	·010	1
D	1897	32·3	67·6	35·3	49·7	−5·0	33·1	35·9	56·3	·072	·213	91	9	—	—
E	1906	32·1	66·4	34·3	48·6	−6·7	29·0	27·3	48·8	·062	·289	90	16	·000	0
F	1903	31·8	67·2	35·4	49·4	−6·0	31·4	32·4	52·2	·071	·235	83	20	·090	2
G	1904	31·6	67·5	35·9	50·0	−6·8	31·1	29·8	50·4	·070	·269	82	14	·000	0
H	1905	31·1	68·8	37·6	51·5	−5·9	32·0	29·6	49·4	·071	·327	91	19	—	—
I	1907	30·3	65·7	35·4	49·2	−5·8	31·4	29·6	52·4	·062	·331	85	15	—	—
J	1909	29·3	65·9	36·6	50·0	−4·9	33·9	34·5	56·6	·063	·285	82	14	·000	0
K	1910	29·1	64·9	35·8	49·2	−6·2	33·7	28·1	58·1	·063	·230	77	29	·525	5
L	1908	27·3	64·9	37·7	49·8	−4·0	35·1	32·2	60·4	·062	·305	81	21	·730	6
M	1900	25·2	63·4	38·2	49·5	−3·9	38·2	32·6	68·3	·070	·206	79	24	1·605	4
N	1899	24·1	62·2	38·1	49·1	−3·0	38·7	32·1	70·6	·060	·257	74	32	·935	9
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

TABLE 2.—Comparison of Meteorological Elements (Year).

	Range of Temp.	Maximum Temp.	Minimum Temp.	Mean Temp.	Range of Dew-point Temp.	Mean Dew-point Temp.	Range of Relative Humidity.	Mean Relative Humidity.	Range of Pressure.	Mean Pressure.	Mean Sunshine.	Mean Cloud.	Mean Rainfall.	Total Rain-fall.
	°	°	°	°	°	°	%	%	Inch.	Inch.	%	%	Inch.	Days.
A	32·6	80·6	48·0	63·6	−0·7	39·0	24·4	44·2	·078	26·137	85	21	·311	33
B	32·0	80·7	48·6	63·8	−0·6	40·1	24·7	46·2	·078	·137	84	22	·695	46
C	31·5	80·6	49·1	63·9	−0·5	40·9	25·0	47·4	·078	·137	83	25	·836	55
D	31·0	80·0	49·0	63·6	−0·4	41·1	24·8	48·2	·078	·135	82	26	·848	58
E	30·6	79·6	49·1	63·4	−0·1	41·4	25·3	49·1	·077	·128	80	28	·998	68
F	30·1	79·3	49·2	63·2	+0·1	41·8	25·3	50·1	·076	·126	80	29	1·201	69
G	29·6	79·4	49·8	63·6	+0·1	42·5	25·1	50·5	·076	·126	79	30	1·361	67
H	29·1	79·2	50·1	63·7	+0·1	43·0	25·0	51·0	·076	·136	80	30	1·454	66
I	28·4	78·7	50·0	63·6	+0·1	43·6	25·3	52·4	·074	·136	79	31	1·429	75
J	27·8	77·9	49·8	63·0	+0·1	44·1	25·7	54·5	·073	·138	77	33	1·553	87
K	27·2	77·4	50·0	62·8	+0·2	44·6	26·1	56·0	·073	·133	76	36	1·683	90
L	26·6	76·8	50·2	62·5	+0·4	45·1	26·4	57·6	·073	·135	75	38	2·026	99
M	25·6	76·0	50·4	62·2	+0·5	46·0	26·6	60·2	·071	·135	74	39	2·434	108
N	24·3	74·8	50·6	61·5	+0·3	47·0	26·2	63·4	·069	·137	72	42	3·086	120
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

TABLE 3.

Harmonic Constants in the Diurnal Curves of Barometric Pressure.

a. For Greater Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	inch	inch	inch	°	°	°
Jan.	30·2	·0383	·0277	·0051	360	153	187
Feb.	30·2	·0364	·0265	·0021	359	151	182
Mar.	28·6	·0295	·0267	·0012	357	155	345
April	29·5	·0228	·0260	·0040	350	159	10
May	31·1	·0235	·0255	·0071	353	157	355
June	30·5	·0234	·0251	·0073	347	156	353
July	32·5	·0269	·0254	·0075	351	154	356
Aug.	34·1	·0301	·0283	·0061	350	157	2
Sept.	34·8	·0327	·0306	·0027	2	165	21
Oct.	32·7	·0350	·0290	·0010	5	168	91
Nov.	33·2	·0373	·0271	·0029	3	164	173
Dec.	30·3	·0370	·0240	·0050	1	161	183
Year	31·5	·0311	·0268	·0043	356	158	—

TABLE 4.

Harmonic Constants in the Diurnal Curves of Barometric Pressure.

β. For Lesser Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	inch	inch	inch	°	°	°
Jan.	24·1	·0313	·0278	·0051	359	157	178
Feb.	24·1	·0286	·0232	·0011	351	154	194
Mar.	23·2	·0260	·0253	·0013	357	152	16
April	23·0	·0212	·0269	·0041	350	154	7
May	23·6	·0186	·0258	·0054	356	160	356
June	26·8	·0199	·0262	·0068	348	160	346
July	27·0	·0237	·0244	·0070	351	154	357
Aug.	31·0	·0261	·0288	·0051	358	157	355
Sept.	29·3	·0275	·0299	·0034	3	166	12
Oct.	28·3	·0326	·0277	·0001	4	166	95
Nov.	29·3	·0355	·0255	·0018	4	166	167
Dec.	27·2	·0362	·0255	·0034	2	157	183
Year	26·4	·0273	·0264	·0037	357	158	—

TABLE 5.

Harmonic Constants in the Diurnal Curves of Temperature.

a. For Greater Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	°	°	°	°	°	°
Jan.	30·2	12·384	2·022	1·212	231	81	30
Feb.	30·2	12·555	2·503	1·134	229	68	20
Mar.	28·6	12·325	2·851	1·098	229	61	19
April	29·5	12·690	3·532	·896	230	62	12
May	31·1	13·352	4·566	·464	231	57	343
June	30·5	12·822	4·498	·290	229	53	292
July	32·5	14·247	4·566	·280	230	52	328
Aug.	34·1	14·771	4·214	·818	229	55	23
Sept.	34·8	15·198	3·544	1·296	230	65	29
Oct.....	32·7	14·000	2·598	1·280	231	78	43
Nov.	33·2	13·965	1·990	1·623	233	95	52
Dec.	30·3	12·645	1·822	1·245	232	85	36
Year	31·5	13·413	3·225	·970	230	68	12

TABLE 6.

Harmonic Constants in the Diurnal Curves of Temperature.

β. For Lesser Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	°	°	°	°	°	°
Jan.	24·1	9·565	1·623	·847	234	78	26
Feb.	24·1	9·954	1·918	·858	230	62	30
Mar.	23·8	9·704	2·384	·720	233	60	22
April	23·0	9·522	2·952	·457	232	58	13
May	23·6	9·477	3·294	·250	231	54	354
June	26·8	11·158	4·233	·179	230	56	302
July	27·0	11·223	3·898	·279	228	53	336
Aug.	31·0	13·031	3·742	·651	228	53	12
Sept.	29·3	12·476	2·789	·926	231	63	28
Oct.....	28·3	11·686	2·174	1·102	233	74	41
Nov.	29·3	12·041	2·026	1·016	235	87	46
Dec.	27·2	11·065	1·639	1·114	233	83	39
Year	26·4	10·909	2·723	·700	231	65	14

TABLE 7.

Harmonic Constants in the Diurnal Curves of Temperature Variability.

a. For Greater Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	°	°	°	°	°	°
Jan.	30·2	3·233	1·046	·927	321	172	120
Feb.	30·2	3·277	1·294	·864	319	158	109
Mar.	28·6	3·218	1·444	·840	319	150	109
April	29·5	3·313	1·828	·685	320	152	102
May	31·1	3·486	2·310	·357	321	147	73
June	30·5	3·348	2·356	·222	319	143	22
July	32·5	3·719	2·364	·218	320	142	58
Aug.	34·1	3·800	2·246	·711	319	144	113
Sept.	34·8	3·968	1·836	·992	320	155	119
Oct.....	32·7	3·655	1·338	·980	321	168	133
Nov.	33·2	3·645	1·030	1·242	323	185	141
Dec.	30·3	3·308	·950	·946	322	174	126
Year	31·5	3·498	1·670	·749	320	158	102

TABLE 8.

Harmonic Constants in the Diurnal Curves of Temperature Variability.

β. For Lesser Ranges of Temperature.

	Range of Temperature.	u_1.	u_2.	u_3.	V_1.	V_2.	V_3.
	°	°	°	°	°	°	°
Jan.	24·1	2·497	·845	·668	324	167	117
Feb.	24·1	2·599	·990	·657	320	152	120
Mar.	23·2	2·530	1·234	·552	323	150	112
April	23·0	2·486	1·528	·349	322	147	103
May	23·6	2·473	1·705	·198	321	145	84
June	26·8	2·913	2·190	·137	320	146	32
July	27·0	2·930	2·018	·207	318	143	65
Aug.	31·0	3·402	1·952	·498	318	142	102
Sept.	29·3	3·257	1·445	·709	321	153	118
Oct.....	28·3	3·098	1·128	·843	323	164	131
Nov.	29·3	3·144	1·049	·778	325	177	136
Dec.	27·2	2·926	·848	·853	323	173	129
Year	26·4	2·855	1·411	·537	321	155	104

TABLE 9.

Hourly Mean Barometric Pressures at 32° F.

a. For Greater Ranges of Temperature.

Hour.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.
Midnight	26·032	26·063	26·081	26·158	26·237	26·278	26·263	26·259	26·183	26·088	26·048	26·042
I.	·026	·061	·076	·156	·234	·276	·262	·256	·179	·081	·042	·037
II.	·021	·058	·073	·152	·231	·274	·257	·251	·173	·074	·039	·034
III.	·020	·055	·067	·145	·226	·272	·256	·247	·167	·073	·038	·035
IV.	·025	·057	·070	·146	·225	·270	·253	·247	·173	·077	·044	·044
V.	·036	·064	·077	·153	·228	·272	·256	·253	·181	·089	·056	·055
VI.	·052	·079	·089	·163	·237	·282	·265	·266	·196	·106	·072	·070
VII.	·066	·093	·102	·177	·250	·294	·279	·281	·212	·120	·084	·080
VIII.	·069	·101	·114	·194	·266	·311	·293	·297	·224	·126	·089	·083
IX.	·066	·101	·117	·201	·276	·323	·305	·306	·227	·127	·087	·079
X.	·062	·096	·115	·198	·277	·326	·307	·307	·221	·118	·078	·070
XI.	·051	·084	·103	·188	·266	·314	·298	·295	·205	·099	·064	·061
Noon	·033	·066	·086	·168	·244	·292	·272	·269	·179	·079	·044	·043
XIII.	·014	·047	·062	·143	·216	·266	·244	·240	·152	·056	·023	·024
XIV.	25·991	·025	·041	·124	·196	·244	·223	·217	·131	·034	·002	·004
XV.	·972	·007	·025	·117	·188	·235	·214	·206	·120	·020	25·987	25·993
XVI.	·958	25·997	·021	·115	·187	·235	·212	·204	·118	·018	·979	·977
XVII.	·953	·993	·024	·116	·192	·240	·216	·208	·123	·022	·980	·977
XVIII.	·964	26·000	·031	·125	·202	·250	·225	·216	·133	·034	·991	·987
XIX.	·982	·017	·044	·136	·215	·257	·236	·228	·150	·051	26·007	26·002
XX.	26·004	·038	·063	·150	·224	·268	·246	·242	·169	·070	·026	·020
XXI.	·021	·054	·075	·158	·231	·274	·253	·250	·180	·080	·041	·035
XXII.	·032	·062	·080	·163	·235	·279	·258	·255	·185	·087	·051	·046
XXIII.	·035	·065	·083	·163	·235	·281	·262	·257	·185	·087	·052	·048
Month	26·020	26·053	26·072	26·155	26·230	26·276	26·256	26·252	26·174	26·076	25·039	26·035
	°	°	°	°	°	°	°	°	°	°	°	°
$M - m =$	30·2	30·2	28·6	29·5	31·1	30·5	32·5	34·1	34·8	32·7	33·2	30·3

TABLE 10.

Hourly Mean Barometric Pressures at 32° F.

β. For Lesser Ranges of Temperature.

Hour.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.	inch.
Midnight	26·036	26·068	26·104	26·165	26·205	26·304	26·266	26·195	26·155	26·107	26·076	26·035
I.	·029	·064	·102	·161	·204	·302	·263	·191	·149	·100	·068	·029
II.	·023	·060	·095	·156	·198	·299	·260	·186	·141	·096	·065	·026
III.	·020	·058	·090	·149	·192	·297	·255	·181	·137	·092	·066	·024
IV.	·026	·060	·089	·148	·191	·296	·253	·180	·138	·097	·071	·029
V.	·040	·068	·095	·153	·195	·298	·255	·186	·148	·106	·083	·040
VI.	·052	·082	·108	·162	·205	·308	·265	·197	·162	·123	·097	·054
VII.	·064	·095	·121	·178	·217	·321	·278	·210	·176	·137	·109	·067
VIII.	·068	·103	·132	·196	·233	·335	·291	·225	·190	·144	·114	·070
IX.	·067	·104	·136	·203	·242	·348	·303	·234	·193	·144	·111	·067
X.	·064	·101	·134	·203	·243	·352	·307	·234	·188	·136	·103	·063
XI.	·053	·092	·124	·194	·231	·341	·295	·222	·174	·120	·089	·051
Noon	·038	·079	·108	·174	·211	·319	·274	·199	·149	·099	·070	·034
XIII.	·021	·060	·087	·149	·185	·291	·246	·171	·124	·079	·049	·014
XIV.	·001	·040	·067	·131	·168	·271	·228	·149	·104	·058	·027	25·993
XV.	25·985	·026	·054	·122	·160	·264	·219	·138	·095	·043	·016	·977
XVI.	·973	·016	·048	·119	·160	·265	·218	·138	·089	·042	·009	·965
XVII.	·973	·014	·049	·120	·166	·270	·221	·141	·100	·045	·012	·965
XVIII.	·979	·024	·057	·127	·176	·280	·229	·153	·112	·055	·023	·976
XIX.	·997	·036	·069	·140	·190	·292	·240	·168	·128	·072	·037	·991
XX.	26·012	·049	·087	·156	·200	·302	·251	·181	·142	·090	·053	26·009
XXI.	·029	·061	·097	·163	·206	·308	·256	·190	·153	·101	·068	·023
XXII.	·041	·068	·103	·168	·210	·312	·262	·197	·156	·106	·076	·036
XXIII.	·043	·069	·106	·169	·210	·313	·262	·199	·156	·108	·076	·038
Month	26·026	26·062	26·094	26·159	26·200	26·304	26·258	26·186	26·144	26·096	26·065	26·024
	°	°	°	°	°	°	°	°	°	°	°	°
M − m =	24·1	24·1	23·2	23·0	23·6	26·8	27·0	31·0	29·3	28·3	29·3	27·2

TABLE 11.

Hourly Mean Temperatures.

a. For Greater Ranges of Temperature.

Hour.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
Midnight	68·1	69·1	62·5	54·5	48·8	41·4	40·8	45·6	53·0	58·2	61·8	67·1
I.	66·7	67·6	61·3	53·4	47·7	40·5	39·6	44·4	51·7	56·8	60·1	65·7
II.	65·5	66·2	60·2	52·3	46·5	39·5	38·5	42·9	50·2	55·1	58·4	64·4
III.	64·3	65·4	59·4	51·3	45·7	38·7	37·7	42·0	49·0	53·9	57·1	63·3
IV.	63·3	64·4	58·5	50·4	44·8	37·8	37·0	41·0	47·9	53·0	55·9	62·4
V.	62·4	63·6	57·6	49·6	43·9	37·1	36·3	40·3	46·9	51·8	54·8	61·4
VI.	63·0	63·1	56·7	48·7	43·2	36·5	35·9	39·4	46·0	52·2	57·5	63·6
VII.	68·6	67·1	58·9	49·5	42·8	35·9	35·4	39·6	49·1	57·9	64·2	68·7
VIII.	73·7	72·7	65·7	56·7	48·6	40·3	40·3	47·0	58·0	64·6	69·9	73·4
IX.	77·7	77·5	70·8	63·2	56·8	48·1	48·7	54·7	63·9	69·3	74·0	77·6
X.	81·2	81·6	74·8	67·6	62·2	53·7	54·6	59·9	68·8	73·1	77·4	81·1
XI.	84·3	84·9	77·9	71·1	66·3	58·0	59·3	64·3	72·5	76·4	80·2	84·2
Noon	86·3	87·3	80·2	73·5	69·2	60·9	62·3	67·1	75·3	78·5	82·2	86·0
XIII.	87·7	89·0	82·0	74·9	71·1	63·2	64·7	69·3	77·3	80·4	83·3	87·3
XIV.	88·1	89·1	82·7	75·6	72·0	64·2	65·8	70·5	78·1	81·1	83·9	87·4
XV.	87·7	89·0	82·7	75·6	72·0	64·4	66·0	70·8	78·2	81·1	84·4	87·3
XVI.	86·7	87·9	82·1	75·0	70·7	63·1	64·9	70·1	77·2	80·0	83·4	86·5
XVII.	85·2	86·4	79·8	71·7	64·9	56·7	59·3	66·4	74·4	77·6	81·4	84·9
XVIII.	82·7	83·3	75·7	65·7	59·0	51·5	52·6	58·8	68·1	73·0	77·7	82·1
XIX.	78·5	78·8	71·5	62·6	56·4	48·8	49·4	54·9	63·6	68·8	73·1	77·9
XX.	75·3	75·7	68·9	60·6	54·3	47·2	47·4	52·4	61·0	66·2	70·1	74·5
XXI.	73·0	73·4	66·7	58·8	52·6	45·5	45·5	50·3	58·3	64·0	67·6	72·1
XXII.	71·2	71·8	65·2	57·3	51·1	44·1	43·8	48·9	56·5	61·9	65·5	70·3
XXIII.	69·6	70·4	63·8	55·7	49·8	42·7	42·3	47·6	55·2	60·2	63·8	68·6
Month	75·5	76·1	69·4	61·5	55·8	48·3	48·7	53·6	61·7	66·5	70·3	74·9

TABLE 12.

Hourly Mean Temperatures.

β. For Lesser Ranges of Temperature.

Hour.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
Midnight	67·9	65·7	62·6	57·6	48·0	44·4	43·8	46·6	52·7	57·4	62·1	66·0
I.	67·0	64·7	61·7	56·8	47·2	43·5	42·7	45·5	51·6	56·1	60·9	65·0
II.	66·1	63·8	60·9	56·0	46·3	42·4	41·8	44·6	50·7	55·1	59·8	63·9
III.	65·5	63·1	60·4	55·3	45·8	41·6	41·0	43·7	49·8	54·4	58·9	62·9
IV.	64·9	62·5	59·8	54·8	45·2	40·8	40·2	42·9	49·1	53·5	57·9	62·0
V.	64·1	61·8	59·3	54·2	44·6	40·0	39·5	42·0	48·4	52·7	56·9	61·1
VI.	64·9	61·6	58·7	53·7	44·0	39·4	39·1	41·2	47·8	53·1	59·0	62·6
VII.	69·0	65·0	60·6	54·1	43·7	39·0	38·3	41·2	50·4	58·0	64·5	67·8
VIII.	72·6	69·2	65·7	59·1	48·0	42·8	42·2	47·8	57·1	63·2	69·0	72·0
IX.	75·8	72·5	69·6	63·9	53·4	50·0	49·4	54·3	62·0	67·2	72·7	75·3
X.	78·7	75·8	72·8	67·3	57·2	55·1	54·2	59·1	66·0	70·7	76·3	78·2
XI.	81·2	78·5	75·5	70·1	60·1	58·6	57·8	62·9	69·1	73·5	78·9	80·9
Noon	82·8	80·3	77·5	72·2	62·3	61·3	60·5	65·6	71·5	75·3	80·7	82·9
XIII.	83·7	81·6	78·5	73·6	63·9	63·2	62·0	67·6	72·9	76·5	82·1	83·8
XIV.	83·9	82·1	79·0	74·0	64·6	64·1	63·1	68·9	73·8	77·1	82·4	84·0
XV.	83·3	82·1	78·9	73·9	64·7	64·1	63·5	69·2	73·9	77·1	81·7	83·9
XVI.	82·4	81·4	78·0	72·9	63·6	62·8	62·4	68·2	73·0	76·1	80·8	83·1
XVII.	81·0	79·9	76·0	69·8	59·3	57·0	57·8	64·8	70·3	74·1	78·5	81·7
XVIII.	79·2	77·1	72·1	65·3	55·2	52·3	52·4	58·5	65·3	70·0	75·3	79·2
XIX.	75·7	73·3	69·0	63·1	53·2	50·0	50·1	55·1	61·8	66·2	71·7	75·3
XX.	73·2	70·9	67·1	61·5	51·7	48·6	48·5	52·9	59·4	63·7	69·1	72·5
XXI.	71·4	69·2	65·6	60·1	50·3	47·3	47·0	51·1	57·3	61·8	67·2	70·6
XXII.	70·1	67·9	64·3	59·1	49·3	46·3	45·8	49·5	55·7	60·2	65·3	68·8
XXIII.	69·0	66·9	63·3	58·1	48·6	45·5	44·9	48·1	54·4	58·9	63·9	67·5
Month	73·9	71·5	68·2	62·8	52·9	50·0	49·5	53·8	60·2	64·7	69·8	73·0

ACTION OF RADIUM SALTS ON GLASS.

By W. A. Douglas Rudge, M.A., F.R.S.S.Af.

(Read October 18, 1911.)

In 1908 the author began some experiments on the action of radium salts on glass, by sealing up a small amount of the salt in thick-walled glass tubes. These have been recently opened and examined, and in view of the interest now being taken in the formation of pleochroic halos in rocks, the results observed may be of some value.

The method employed was as follows:—

Some pieces of barometer tubing were selected, and a number of pieces about 5 cm. in length cut off. In some cases the radium salt was hermetically sealed in by fusing the ends of the glass, and in others the ends of the tube were merely plugged by paraffined cork.

The radium salt was one purchased from Messrs. Harrington in 1903, when it was stated to contain $\frac{1}{1000}$ of its weight of radium bromide. On being tested against black oxide of uranium, it has at the present time an activity about 5,000 times as great as that substance.

Two kinds of tubing were employed, one which showed a *very faint* pink tinge when looked at through the tube endwise, while the other had a pale greenish colour, but both colourations were very slight. After sealing the tubes were put away in a box, to which no light was admitted. Two control tubes of each sample were also used, one being kept in the dark and the other exposed to the brilliant sunlight of South Africa. This last was done because ordinary white glass exposed on the veldt acquires a dark amethyst tint in a few months. Unfortunately these samples were swept away in a storm.

On examining the tubes containing the radium from time to time, a progressive colouration was seen to be developed, more particularly at the end of the tube where the radium was lying, but it spread for some distance above. In one case, for example, the radium salt occupied a portion of tube to the extent of not more than 2 mm., while the colouration extended for 8 mm., diminishing gradually in intensity. On observing this the

tubes were occasionally turned over, so as to spread the colouration over as large a surface as possible.

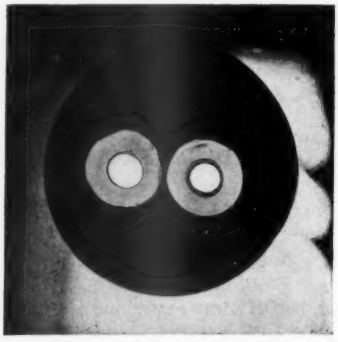


FIG. 1.
M = 1·1 Diameters.

On making a close examination of these tubes a marked difference was seen in the manner in which the colouration had developed in the two kinds of glass; the photographs show this difference very clearly.

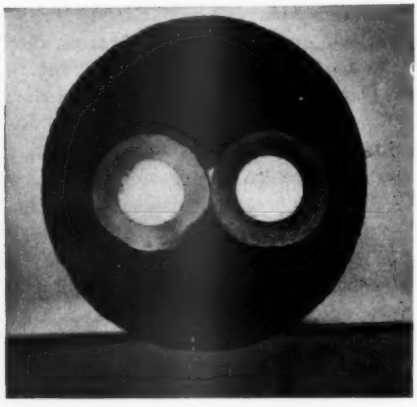


FIG. 2.
M = 1·5 Diameters.

Pieces of the radium-coloured tube and of the control sample were cut off, the ends ground and roughly polished, cover glasses being placed over

the ends and kept in place by a little cedar oil. The two tubes were mounted side by side in a cork and photographed together, a Zeiss microplanar lens being used for the purpose.

Fig. 1 shows the two pieces of pink glass, and Fig. 2 the green. The dark patches in the left-hand tube in Fig. 2 are due to refraction at cracks in the glass. In Fig. 1 it can be seen that a dark zone is formed close to the bore of the tube, while in Fig. 2 the darkening extends to a greater distance without being so intense in any place. The real intensity of the colouration, as seen visually, is not correctly indicated by the photographs. The magnifications are about 1·1 for the pink tube and 1·5 for the green tube.

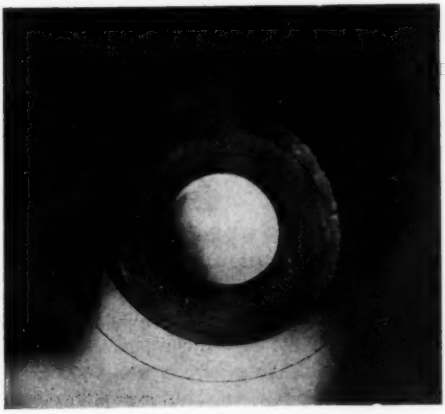


FIG. 3.
M = 3·5 Diameters.

On submitting No. 1 to a magnification of about 12 diameters a very remarkable appearance presented itself. The colouration was seen to have proceeded in a series of zones, one zone being clearly marked off from the rest, as shown in Fig. 3. Considerable difficulty was experienced in getting these zones clearly defined in the photograph, but this was accomplished at last by aid of isochromatic plates in conjunction with a light filter.

The innermost zone is very dark, while the succeeding zones show a gradual fading of the colour, which persists, however, right to the outside of the tube. The external diameter of the pink tube was 9·32 mm., the internal diameter 4·35 mm., and the thickness of wall 2·48 mm. The thickness of the first dark zone was 0·27 mm., and of the second 0·33 mm.

The zonal structure was not developed by the action of the radium, as it can be traced in the control tube, but not of course very distinctly, as the glass was not perfectly homogeneous, a sort of schistose structure being present. There was evidently some obstacle to the free passage of the α-particles, encountered at the junction of the layers of material.

The colouration extends into the glass for over 2 mm., and at all points of optical discontinuity a sharp change in the colouring power occurred, as though there was a strongly resistant layer at the junction of the two zones. From Professor Rutherford's paper (*Phil. Mag.*, Jan., 1910) one might conclude that the maximum depth of the colouration should be proportional to the range of the α-particles, and he gives the number 0·041 as the distance to which the α-particles should penetrate in glass.

If the α-particles fired into the innermost layer of the tube remain embedded there, could they impart a radio-activity to the layer, which in its turn would send off more particles, thus making the second layer active, and so on? This point might have been elucidated had the tube been examined regularly during the two years. An experiment has been started in which the tube will be examined at intervals.

The purple colouration I take to be due to some manganese compound, formed by the action of the rays on the glass in the one case, and in the other the increase in depth of the green colouration, to the possible reduction of a ferric compound to a ferrous one. Manganese in small quantities is frequently added to glass used for making tumblers, etc., in order to counteract the green colour due to iron compounds; the intense colouring power of the higher oxides of manganese is well known.

Plugging the tube with cork seemed quite as efficacious as hermetically sealing; the colouring did not proceed much beyond the cork. The photograph, Fig. 3, is of a corked tube, and the intensity of the colouration should be relatively greater than that shown, as the coloured portion of the tube was only 1·5 cm. in length, whilst the control tube was 3·2 cm.

The amount of emanation present in the tube cannot have been very large at any time, as, assuming the purity of the radium salt to be $\frac{1}{1000}$, this would give off a total amount of emanation which, in two years, would have approximately amounted to $\frac{1}{1000} \times \cdot3 \times \cdot1 \times \cdot730$ cb. mm. of helium.* As this was continually decaying, and, also, in the case of the corked tubes, escaping, the amount present at any one time must have been very small, although it is most probable that the action is a cumulative one. The nature of the colouration clearly depends on the

* This would be the amount of emanation from a gramme of the salt. The actual amount used was only a few centigrammes.

nature of the glass. Further experiments are being proceeded with on various kinds of glass and other materials.

Professor Joly, in the *Phil. Mag.* for Feb., 1910, gives an account of an appearance similar to that just described, in a specimen of greisen. From the description of the sets of halos, it seems that a structure must exist in the crystal section similar to that occurring in the glass tube of my observations, but here again the action is limited to a small distance. A piece of glass tubing, owing to the method of manufacture, will probably be in a state of strain between the two surfaces, from which relief may be obtained by the zonal structure being formed. In the case of the crystal

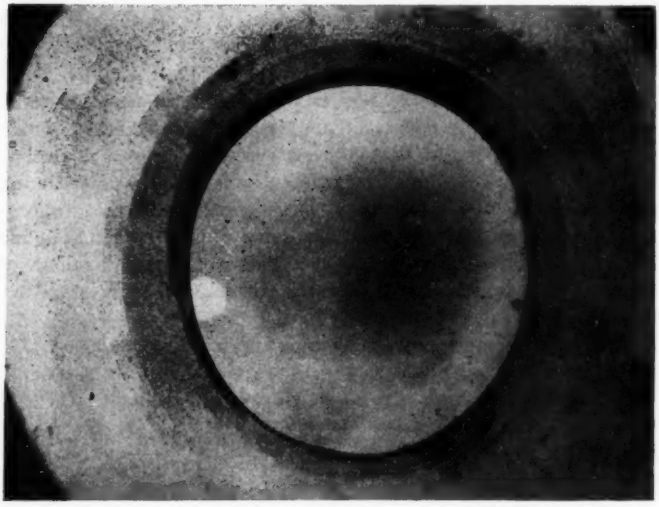


FIG. 4.
M = 12 Diameters.

referred to by Professor Joly, since it separated from the magma, it would have been subject to some severe strain when the whole mass had become solid, on which a zonal structure may have been developed. The two surfaces of adjacent zones would naturally form boundaries to materials which are in some slightly different physical state, and so the α or other particles might experience a difficulty in crossing the boundaries. If the surface layers of the different zones were in a state of great tension they might act as though their densities were much greater than that of the mass of the material enclosed between their surfaces, and thus the α particles would experience a check to their velocity on crossing the boundary.

The foregoing was written in August, 1910, and since then observations have been taken upon other tubes in which impure radium salt had been sealed. The glasses used were: (1) a greenish coloured barometer tubing, (2) white thermometer tubing, (3) Jena combustion tubing, (4) tubing of the same kind used in the experiments detailed, (5) ordinary soft glass tubing. After introduction of the radium preparation the tubes were plugged with cork, and small cover-glasses fastened on the ends with Canada balsam. Control samples of tubing were cut off at the same time, which were kept in the dark. These were made of various lengths, so that any increase in the depth of colouring produced by the action of the radium could be contrasted with the original depth of colour by comparing the experimental tube with others of different length in the manner usual in colourimetric methods.

1. The length of the experimental tube was 3·3 cm., small plugs of cork 0·3 cm. closed each end, and the radium salt occupied about 0·3 cm. The control tubes were 4, 5, 6, and 8 cm., and the time taken for the depth of colouration to reach that shown by a greater length of control tube, which had not been acted upon by radium, found. This time cannot be stated with any degree of certainty, but a progressive colouration was shown, and the contrast presented the same difficulty as that found in comparing intensities of illumination of lights of different colour. The green colour was changed to a browner shade, especially close to the inner wall of the tube.

The following figures must be taken as approximate only:—

Time in months.	Length of control tube to match colour.
0	3·3
3	4·0
6	5·0
8	6·2
12	8·0

A brown layer was formed close to the inner wall of the tube, and this gradually merged into the general green colour of the glass and reached the outer wall. The thickness of the wall was 0·23 cm.

2. Jena hard glass tubing. This glass had a bluish green-colour, and no change occurred in twelve months in a tube 2·1 cm. in length.

3. White thermometer tubing 2·2 cm. in length. This specimen was nearly white. A faint violet colouration was seen in the layer immediately surrounding the bore, and a darkening occurred throughout the mass. The length at the end of twelve months of the control tubing which matched that of the experimental tube was 5 cm.

4. This specimen was of the same kind of glass as that referred to in the first part of the paper. The tube was 2 cm. in length, and the free space when plugged about 1·5 cm. The radium salt got mixed up with the balsam used for sealing, and was rather irregularly spread over about 0·3 cm. The action extended along the tube for a greater distance than that occupied by the radium, even penetrating to the portion covered by the cork. With this tube the progressive colouration could be followed and the time for each successive zone to be developed noted.

In 20 days a decided colouration was visible, and this extended for a certain distance and then stopped abruptly at the end of the first layer of the glass. In 53 days the second zone could be traced and was quite distinct at the end of 120 days, when the third zone had begun to show itself. In 250 days the third zone was well marked, and at the present time, 337 days from the commencement, five zones can be seen. The colouration does not yet extend right through the wall of the tube. The width of the zones does not change with time, but the depth of colouration does.

The measurements made on the tube were as follows:—

Internal diameter	3	mm.
External „	8·5	„
Thickness of wall	2·5	„
1st and deepest coloured zone	0·05	„
2nd zone	0·1	„
3rd „	0·3	„
4th „	0·5	„

The width of a zone is not uniform, as it depends upon the original zonal structure present in the glass, and the values given are average ones, as a reference to Fig. 3 will show. The zonal structure is not developed by the radio-active action.

5. This was a specimen of fairly homogeneous glass, without zonal structure, and it showed a progressive depth of colouration from the inner to the outer wall. The depth of colour developed in a given time was greater than that of any other glass examined.

From the papers of Professors Joly and Rutherford it might be inferred that they consider the colouration as being due to the α particles alone. If this is so, then the range of the α particles must be much greater than that indicated, for there is no question as to the depth of penetration in the glass tubes. But why is the development of the colour to be limited to the α particles? The β and γ rays pass through the material and clearly must exert some influence; in fact, the total change must be due to this combined effect.

It seems a matter of interest to know that very small amounts of a radium salt can give rise to such definite changes in colour. A tiny speck of the radium salt, weighing less than a milligram and very impure, will show a distinct colouration in a capillary tube at the end of 40 days. The small amounts of radium present in ordinary rock may thus well be capable in geological time of giving rise to the pleochroic halos.

NOTES ON THE GENUS *FICUS* (TOURN.), LINN.

By Joseph Burtt-Davy, F.L.S., F.R.S.S.Af., F.R.G.S.

(With Plates XII., XIII.)

(Read October 18, 1911.)

In the *Kew Bulletin* for 1908 (No. 4, p. 165) I discussed the relationship of the Wonderboom, as the result of studies in the herbaria of Kew and Zurich. At that time I was unable to arrive at any definite conclusion, but subsequent study of the tree at different seasons and under varying conditions shows clearly that it is a distinct species, for which I propose the name of *Ficus Pretoriæ*.

Ficus Pretoriæ, Burtt-Davy, sp. nov.—Arbor majuscula, umbrosa, ad 60 ped. alt., ramis patentibus in comam latiusculam expansis, ramulis glabris, cortice fusco, foliis persistentibus, petiolatis, ellipticis vel oblongis, coriaceis, glabris, integerrimis, apice obtusis vel acutis, basi truncatis vel rotundatis vel vix sub-cordatis, petiolis eglandulosis 1–1½ poll. long., receptaculis tribus in axillis, densis, sub-globosis, glabris, verrucosis, 3 lin. diam. Gemma terminali longe acuminata, glabra. *F. salicifolia Vahl var australis Warb. non F. australis, Willd.*

Spreading, umbrageous, evergreen tree, up to 60 feet high; branchlets glabrous, reddish. *Leaves* coriaceous, bluish-green, entire, glabrous, 3–5 in. long, 1¼–2¼ in. wide, oblong or elliptic, acute or obtuse, rounded to cuneate at base (not, or scarcely, cordate); marginal vein conspicuous on both sides, remote from the margin; petioles slender, 1½ in. long, glabrous; stipules long-acuminate, ½ in. long, glabrous. *Receptacles* in threes, axillary, arranged along the whole length of the branchlet, globose, about 3 lines diameter, pale green, becoming whitish when ripe, glabrous, spotted with whitish pustules, sessile or very shortly pedunculate.

Transvaal. Magaliesberg at the Wonderboom-poort, *Burtt-Davy*, 2806, 2645, 2750, &c.; known locally as the Wonderboom.

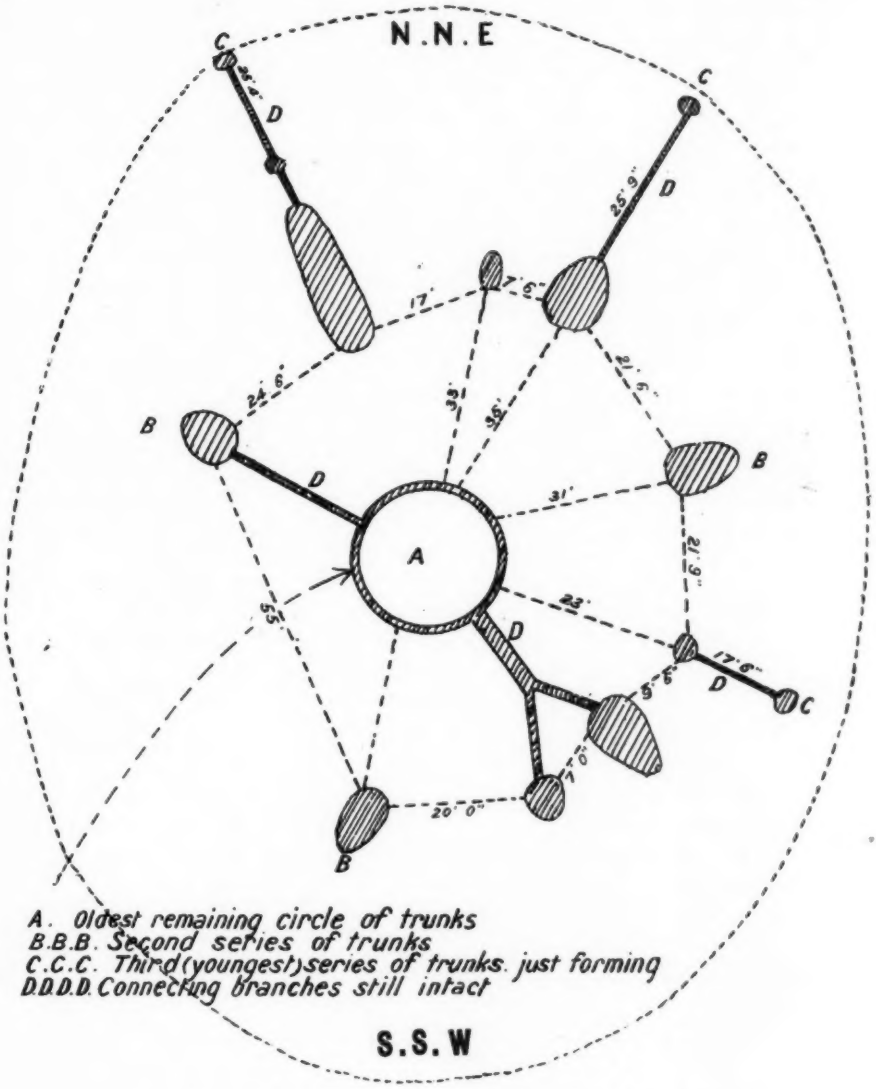
The Pretoria "Wonderboom" was illustrated from photographs in the *Transvaal Agricultural Journal*, vol. iv., plates 3, 4, and 5, October, 1905,

and in the same publication Mr. Harold W. F. Wager, F.R.S., F.L.S., gave the following interesting account of it:—

"The 'Wonderboom' is a remarkable tree. It forms a large hemi-

Ficus Pretoriæ Burtt-Davy.

spherical mass covered with evergreen leaves and small figs. Its diameter from NNE. to SSW. is 162½ feet, and from E. to W. 141½ feet. Its height, as estimated by means of triangles of Kaffir whips, was 67 feet.



Diagrammatic Plan of Wonderboom. Showing position of new Growths.

"The tree spreads in a peculiar manner. Some of the branches from the centre spread out laterally in a radial direction and gradually droop towards the ground. At a distance of about 30 feet they come into contact with it and send out roots from which new groups of stems arise. From these other branches may be given off, still in the same radial direction, and these coming in contact with the ground may become rooted, in their turn, and send up a third group of stems.

"From measurements made on the spot we found an inner ring of nine groups of stems surrounding the main central mass, three of them still connected to it by their drooping branches. The circumference of the central mass of stem is 81 feet, and the second group forms approximately a circle at an average distance of about 30 feet. Beyond the ring there were three other groups at a distance of about 25 feet from the outside of the ring still connected by the branches from which they had originated."

While recently working over some South African material of the genus *Ficus*, I have been able to identify from the descriptions and illustrations some of Mr. T. R. Sim's Portuguese East African species with species which occur in extra-tropical South Africa. The following species are described and figured in the "Forest Flora and Forest Resources of Portuguese East Africa," by T. R. Sim, F.L.S.; Aberdeen, 1909:—

F. howardiana, Sim, occurs sparingly in Swaziland, and at Nelspruit, Transvaal. It is No. 176 of my list of *Native Trees of the Transvaal.*

F. picta, Sim, agrees well with *F. soldanella*, Warb., a species found in similar situations along the Magaliesberg.

F. montana, Sim, is *F. Sonderi*, Miq., also met with in Natal (Camperdown) and Bechuanaland.

F. umbrosa, Sim, resembles in its remarkable foliage a species which grows sparingly on the Berea at Durban, but which differs in some particulars from Mr. Sim's description, as pointed out to me by Miss Franks, who has been watching the tree during the present season, and has recently been able to obtain fruiting material; it may prove to be a distinct species, but further investigation is needed.

F. utilis, Sim, appears to be the tree which was formerly planted so extensively as a street tree in the lower parts of Durban, but whether indigenous to Natal or introduced from farther north, no one seems to know.

West, Newman proc.

THE PRETORIA "WONDERBOOM."
Ficus Pretoriæ Burtt-Davy.

West, Newman proc.

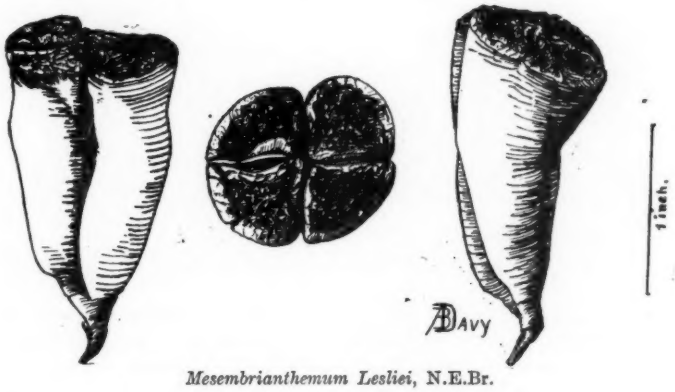
INTERIOR VIEW OF THE PRETORIA "WONDERBOOM."
Ficus Pretoriæ Burtt-Davy.

A NEW SPECIES OF *MESEMBRIANTHEMUM* FROM THE TRANSVAAL.

By Joseph Burtt-Davy, F.L.S., F.R.S.S.Af.

(Read October 18, 1911.)

About three years ago my friend Mr. T. N. Leslie, of Vereeniging, sent me specimens of a peculiar *Mesembrianthemum* found among the pebbles of the Dwyka Conglomerate at Vereeniging in the Heidelberg District. This did not fit the description of any known species, but



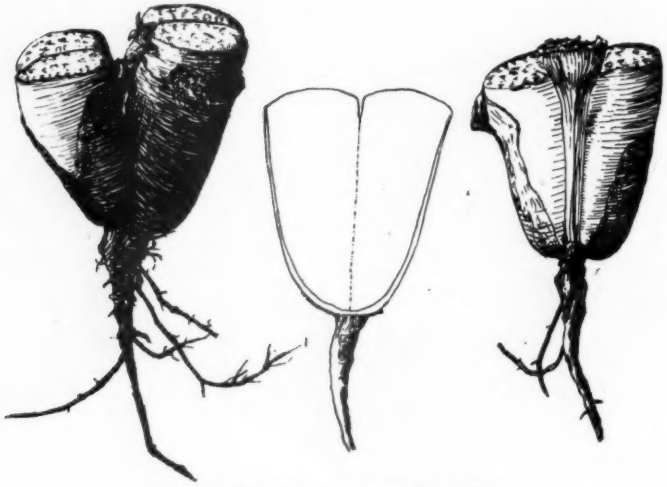
Mesembrianthemum Lesliei, N.E.Br.

unfortunately I was unable to obtain flowers until a year ago. The material was then sent to Kew, and was pronounced by Mr. N. E. Brown, A.L.S., to represent an undescribed species. Mr. Brown has kindly drawn up the following description of the species:—

"*Mesembrianthemum Lesliei*, N. E. Brown, sp. nov.—Corpuscula caespitosa, crasse carnosa, late compresso-obconica, apice perfecte truncata cum fissura transversa percursa, 1·5–2·5 cm. alta, apice 2·5–3 cm. longa et 1·8–2·3 cm. lata, levia, glabra, lateribus pallide purpureo-cineras-

centibus, apice sordide olivaceo-viridi maculis parvis ramosis vel subdendriticis ochraceo-salmoneis notato. Flores 2·5 cm. diam. lutei. Calyx 5-lobus; tubus vix exsertus; lobi 7–8 mm. longi, ovato lanceolati, subobtusi. Petala 1–1·2 cm. longa, linearia, obtusa, lutea, apice rubro-auriantiaco tincta. Stamina numerosissima alba.

"Plant consisting of a tuft of crowded compressed-obconic fleshy leaves, perfectly flat and marked with a transverse fissure on the top, each about $\frac{3}{4}$–1 in. high and 1–1$\frac{1}{8}$ in. in the longer diam. and $\frac{3}{4}$–$\frac{7}{8}$ in. in the shorter diam. of the flat top, smooth, not at all tuberculate on the top, glabrous, with the sides and the fissure pale purplish-grey



Mesembrianthemum Lesliei, N.E.Br.

without markings, and the top dull olive-green, marked all over with small branched spots of a peculiar ochreous-salmon colour. Flowers about 1 in. in diam., with the ovary scarcely exserted. Calyx with 5 lobes about 3$\frac{1}{2}$–4 lin. long, ovate-lanceolate, obtusely pointed. Petals 4$\frac{1}{2}$–5$\frac{1}{2}$ lin. long, linear, obtuse, bright yellow, shading into reddish-orange at the tips, pinkish on the underside. Stamens numerous, not connivent, white.

"*Transvaal.* Vereeniging, *Burtt-Davy* 5613! *Leslie* in T.D.A. Herb. No. 4937! Griqualand West, Windsorton, *Marloth* 4870!

"This species is allied to *M. Hookeri*, Berger (*M. truncatellum*, Hook. f. in *Bot. Mag.* t. 6077), but is at once distinguished by its smaller size and smooth (not warted) top."

This plant has since been collected along the diamondiferous gravels near Bloemhof. It thus appears to be confined to the shallow depression (valley it can scarcely be called) of the Vaal River, for a considerable distance of its course. So far I have only found it among pebbles, the colouring and appearance of which it so closely simulates that it requires considerable practice to detect the plants; when once recognised, however, the regularity of outline distinguishes them from the pebbles.

The body of the leaf is about an inch high, and is embedded in the soil, so that only the truncated apex is visible. The leaves are renewed yearly, a new pair pushing out from between, and at right angles to, the old ones, the latter rapidly losing their succulence and withering away, having the appearance of a dried sheath surrounding the new leaves.

THE RESULTANT OF A SET OF HOMOGENEOUS LINEO-LINEAR EQUATIONS.

By Thomas Muir, LL.D., F.R.S.

(Read March 20, 1912.)

1. In several of Sylvester's writings of the year 1863 there crop up references to a peculiar entity called a "double determinant." At the beginning of a paper "On a Question of Compound Arrangement," * he says that the question arose in the course of his "successful but as yet unpublished researches into the Theory of Double Determinants"; and, having enumerated two results in connection with the said question, he appends an observation to the effect that "a double determinant means the resultant of a system of $m+n-1$ homogeneous equations, each containing mn terms, and linear in respect to each of two systems of m and n variables taken separately but of the second order in respect to the variables of these two systems taken collectively." He also states that it can be represented by an ordinary determinant of the $(m+n-1)$th order, whose elements are sums of simple determinants of the same order. Here, however, some error must have crept in, as he says quite correctly that the degree of the resultant in respect of the coefficients is

$$\frac{(m+n-1)\,!}{(m-1)\,!\,(n-1)\,!},$$

a number which implies that the order-number first mentioned should not be $m+n-1$ but

$$\frac{(m+n-2)\,!}{(m-1)\,!\,(n-1)\,!}.$$

His observation concludes with the statement that the only case previously considered is the case where $m, n = 2, 2$, and that for this Cayley is responsible.†

* *Proceed. R. Soc. of London*, xii. pp. 561–563; or *Collected Math. Papers*, ii. pp. 325–326.

† Cayley's eliminant is of the 2nd order with elements of the 3rd order, in agreement with our surmise. See *Cambridge and Dub. Math. Journ.*, ix. p. 171.

2. The interest of the matter does not at all lie in the difficulty of effecting elimination, but in identifying the peculiar form of eliminant referred to by Sylvester, and in ascertaining the process devised for establishing it.

Thus, taking a set of equations illustrating the case where $m, n = 3, 2$, namely,

$$\left.\begin{aligned} a_1\xi u + a_2\eta u + a_3\zeta u + a_4\xi v + a_5\eta v + a_6\zeta v = 0 \\ b_1\xi u + b_2\eta u + b_3\zeta u + b_4\xi v + b_5\eta v + b_6\zeta v = 0 \\ c_1\xi u + c_2\eta u + c_3\zeta u + c_4\xi v + c_5\eta v + c_6\zeta = v0 \\ d_1\xi u + d_2\eta u + d_3\zeta u + d_4\xi v + d_5\eta v + d_6\zeta v = 0 \end{aligned}\right\}$$

and writing each equation in the form

$$(a_1u + a_4v)\xi + (a_2u + a_5v)\eta + (a_3u + a_6v)\zeta = 0$$

we readily obtain four partial resultants like

$$\begin{vmatrix} a_1u+a_4v & a_2u+a_5v & a_3u+a_6v \\ b_1u+b_4v & b_2u+b_5v & b_3u+b_6v \\ c_1u+c_4v & c_2u+c_5v & c_3u+c_6v \end{vmatrix} = 0,$$

or

$$|a_1b_2c_3|u^3 + \{|a_1b_2c_6| + |a_1b_5c_3| + |a_4b_2c_3|\}u^2v + \{|a_1b_5c_6| + |a_4b_2c_6| + |a_4b_5c_3|\}uv^2 + |a_4b_5c_6|v^3 = 0,$$

and thence finally

$$\begin{vmatrix} |a_1b_2c_3| & |a_1b_2c_6| - |a_1b_3c_5| + |a_2b_3c_4| & |a_1b_5c_6| - |a_2b_4c_6| + |a_3b_4c_5| & |a_4b_5c_6| \\ |a_1b_2d_3| & |a_1b_2d_6| - |a_1b_3d_5| + |a_2b_3d_4| & |a_1b_5d_6| - |a_2b_4d_6| + |a_3b_4d_5| & |a_4b_5d_6| \\ |a_1c_2d_3| & |a_1c_2d_6| - |a_1c_3d_5| + |a_2c_3d_4| & |a_1c_5d_6| - |a_2c_4d_6| + |a_3c_4d_5| & |a_4c_5d_6| \\ |b_1c_2d_3| & |b_1c_2d_6| - |b_1c_3d_5| + |b_2c_3d_4| & |b_1c_5d_6| - |b_2c_4d_6| + |b_3c_4d_5| & |b_4c_5d_6| \end{vmatrix} = 0. \quad (A)$$

Here we have first eliminated ξ, η, ζ, and thereafter u^3, u^2v, uv^2, v^3: but we might just as well have eliminated u, v to begin with, and thereafter ξ^2, η^2, ζ^2, $\xi\eta$, $\eta\zeta$, $\zeta\xi$, the result then being

$$\begin{vmatrix} |a_1b_4| & |a_2b_5| & |a_3b_6| & |a_2b_6| + |a_3b_5| & |a_1b_6| + |a_3b_4| & |a_1b_5| + |a_2b_4| \\ |a_1c_4| & |a_2c_5| & |a_3c_6| & |a_2c_6| + |a_3c_5| & |a_1c_6| + |a_3c_4| & |a_1c_5| + |a_2c_4| \\ |a_1d_4| & |a_2d_5| & \cdots & \cdots & \cdots & \cdots \\ |b_1c_4| & \cdots & \cdots & \cdots & \cdots & \cdots \\ |b_1d_4| & \cdots & \cdots & \cdots & \cdots & \cdots \\ |c_1d_4| & \cdots & \cdots & \cdots & \cdots & \cdots \end{vmatrix} = 0. \quad (B)$$

In general the compound determinant in (A) would be of the order $(m+n-1)!/m!\,(n-1)!$, and the order of the determinants forming its elements would be m: similarly in (B) the order of the compound deter-

minant would be $(m+n-1)!/n!\,(m-1)!$ and the order of the determinants forming the elements would be n. In either case the degree of the resultant would thus be $(m+n-1)!/(m-1)!\,(n-1)!$, as we know that it ought to be.

3. Now, neither of these forms is the form which Sylvester considered satisfactory. In a paper "On a Theorem relating to Polar Umbræ,"* the nature of which may be more readily recognised by saying that it concerns a vanishing product of what Hankel afterwards called "alternate numbers," he makes the remark that "this is the fundamental theorem by aid of which I obtained the resultant of a lineo-linear system of equations in its most perfect form. It is easy to obtain two different solutions, each of them unsymmetrical in respect of the data of the question: the conversion and fusion of each of these into one and the same determinant, symmetrical in all its relations to the data, is effected instantaneously by a process derived from the above theorem."

Doubtless the two solutions which Sylvester here depreciates are those which we have just given: but we are still kept in the dark as to the solution which he considered superior.

4. Meanwhile Cayley had contributed to the *Philosophical Magazine* a theorem or two on so-called "canonic roots," which led Sylvester to publish a sequel: and in this sequel,† after referring to the contents of Cayley's paper, he says: "This is the essence of the matter communicated by Mr. Cayley: but subsequent successive generalisations of the theorem have led me on, step by step, to the discovery of a vast general theory of double determinants, that is, resultants of bipartite lineo-linear equations, constituting, I venture to predict, the dawn of a new epoch in the history of modern algebra and the science of tactic." In the course of the account which follows we see how in his investigation on "canonic roots" a special set of lineo-linear equations ($m, n = 3, 2$) had turned up, why elimination was necessary, and how the idea of double determinants had arisen. Further, although the coefficients of the set of equations in question are not independent, being those of a persymmetrix matrix, we are able from an examination of the resultant obtained to guess what it would have been had the coefficients been perfectly general, like those we have used above, namely,

$$\begin{vmatrix} |a_1b_2c_3d_4| & |a_1b_3c_4d_5| - |a_1b_2c_4d_6| & |a_1b_4c_5d_6| \\ |a_1b_2c_3d_5| & |a_2b_3c_4d_5| - |a_1b_2c_5d_6| & |a_2b_4c_5d_6| \\ |a_1b_2c_3d_6| & |a_2b_3c_4d_6| - |a_1b_3c_5d_6| & |a_3b_4c_5d_6| \end{vmatrix} = 0. \quad \text{(C)}$$

* *Proceed. R. Soc. London*, xii. pp. 563–565; or *Collected Math. Papers*, ii. pp. 327–328.

† *Philos. Magazine*, xxv. pp. 453–460; or *Collected Math. Papers*, ii. pp. 331–337.

The superiority of this over the two others is at once apparent. It is not only that the eliminant is of lower order: there is the further advantage that the determinants which compose its elements are all *primary* minors of the given array of coefficients.

If we use

$$(\alpha, \beta, \gamma, \dots)(m, n, r, \dots)$$

to stand for

$$\alpha m, \beta m, \gamma m, \dots, \alpha n, \beta n, \gamma n, \dots, \alpha r, \beta r, \gamma r, \dots$$

and denote a primary minor of an oblong array by the numbers of the columns which it occupies in the array, the result may be formulated thus:

The resultant of the set of equations

$$\begin{vmatrix} a_1 & a_2 & \dots & a_6 \\ b_1 & b_2 & \dots & b_6 \\ c_1 & c_2 & \dots & c_6 \\ d_1 & d_2 & \dots & d_6 \end{vmatrix} (\xi, \eta, \zeta)(u, v) = 0$$

is

$$\begin{vmatrix} 1234 & 1345-1246 & 1456 \\ 1235 & 2345-1256 & 2456 \\ 1236 & 2346-1356 & 3456 \end{vmatrix} = 0.$$

A widely general result including this—in fact, the result for the case $m, n=m, 2$—was given by me in 1905 before the conception of double determinants had been brought to my notice.*

5. So far as can be learned, Sylvester never returned to the subject. The question therefore remains as to how the result just given can be established. According to himself, he obtained it by a sort of condensation-process performed on either of the other two: but what the exact nature of this process was it is hard to guess, and practically no help is got from being told that it was dependent on his theorem about polar umbræ.

6. It is therefore all the more interesting to know that it can be obtained quite independently of the two others and as easily as either. For, writing the four given equations in the form

$$a_1 u\xi + a_4 v\xi + (a_2 u + a_5 v)\eta + (a_3 u + a_6 v)\zeta = 0,$$

and eliminating $u\xi$, $v\xi$, η, ζ, we have

$$\begin{vmatrix} a_1 & a_4 & a_2 u + a_5 v & a_3 u + a_6 v \\ b_1 & b_4 & b_2 u + b_5 v & b_3 u + b_6 v \\ c_1 & c_4 & c_2 u + c_5 v & c_3 u + c_6 v \\ d_1 & d_4 & d_2 u + d_5 v & d_3 u + d_6 v \end{vmatrix} = 0,$$

* *Transac. R. Soc. Edinburgh*, xlv. pp. 1–7; and *Messenger of Math.*, xxxv. pp. 118–121.

whence

$$|1423|u^2+\left\{|1426|+|1453|\right\}uv+|1456|v^2=0.$$

Similarly there is obtained

$$|1253|u^2+\left\{|1256|+|4253|\right\}uv+|4256|v^2=0,$$

by eliminating ξ, $u\eta$, $v\eta$, ζ: and

$$|1236|u^2+\left\{|1536|+|4236|\right\}uv+|4536|v^2=0,$$

by eliminating ξ, η, $u\zeta$, $v\zeta$. Elimination of u^2, uv, v^2 from these three partial resultants is then all that is required.

7. Further, this process of ours is of perfectly general application. The $m+n-1$ given equations being

$$\begin{vmatrix} a_1 & a_2 & \dots & a_{mn} \\ b_1 & b_2 & \dots & b_{mn} \\ \vdots & \vdots & & \vdots \\ (m+n-1 \text{ rows}) & & & \end{vmatrix}(x_1, x_2, \dots, x_m)(y_1, y_2, \dots, y_n) = 0$$

we eliminate the x's in such a way as to obtain a set of

$$(m+n-2)\,!/(m-1)\,!\,(n-1)\,!$$

equations linear and homogeneous in the compound variables

$$y_1^{m-1},\quad y_1^{m-2}y_2,\quad \dots,\quad y_n^{m-1},$$

and then at one stroke eliminate these also. Or, we may begin by eliminating the y's in such a way as to obtain a set of equations linear and homogeneous in the compound variables

$$x_1^{n-1},\quad x_1^{n-2}x_2,\quad \dots,\quad x_m^{n-1},$$

and then eliminate the x's.

The number of compound variables in the one set is the same as in the other, because the number of combinations of m things taken $n-1$ together with repetitions allowed is the same as the number of the similar combinations of n things taken $m-1$ together, namely,

$$(m+n-2)\,!/(m-1)\,!\,(n-1)\,!$$

Further, it is most important to notice that whether we begin with the elimination of the x's or the elimination of the y's there is no real

difference in the result, the rows of the one eliminant being the columns of the other.

8. The mode of effecting the preliminary set of eliminations is well worth a little attention. To make it clear, let us take the case where $m, n = 3, 3$, namely, the case of the elimination of $\xi, \eta, \zeta, u, v, w$ from the five equations

$$\left.\begin{aligned} a_1\xi u + a_2\eta u + a_3\zeta u + a_4\xi v + \ldots + a_9\zeta w = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ e_1\xi u + e_2\eta u + e_3\zeta u + e_4\xi v + \ldots + e_9\zeta w = 0 \end{aligned}\right\}$$

Arranging the equations in the form

$$a_1\xi u + a_2\eta u + a_3\zeta u + (a_4\xi + \ldots)v + (a_7\xi + \ldots)w = 0,$$

we eliminate $\xi u, \eta u, \zeta u, v, w$, and obtain

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4\xi + a_5\eta + a_6\zeta & a_7\xi + a_8\eta + a_9\zeta \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots \\ e_1 & e_2 & e_3 & e_4\xi + e_5\eta + e_6\zeta & e_7\xi + e_8\eta + e_9\zeta \end{vmatrix} = 0,$$

whence there results

$$\begin{aligned} &12347\xi^2 + 12348\xi\eta + 12349\xi\zeta \\ &+ 12357\eta\xi + 12358\eta^2 + 12359\eta\zeta \\ &+ 12367\zeta\xi + 12368\xi\eta + 12369\zeta^2 = 0. \end{aligned}$$

By the elimination of $u, \xi v, \eta v, \zeta v, w$, we obtain a similar equation, and by the elimination of $u, v, \xi w, \eta w, \zeta w$ a third. We have thus three equations in the six compound variables $\xi^2, \eta^2, \zeta^2, \xi\eta, \eta\zeta, \zeta\xi$, and have therefore to seek for other three. It is the obtaining of the latter three that is most interesting.

Putting the given equations in the form

$$(a_1\xi + a_2\eta)u + a_3\zeta u + a_4\xi v + (a_5\eta + a_6\zeta)v + (a_7\xi + a_8\eta + a_9\zeta)w = 0,$$

eliminating $u, \zeta u, \xi v, v, w$, and proceeding as before, we reach a cubic in ξ, η, ζ, every term of it involving η except two, namely,

$$13467\xi^2\zeta, \quad 13469\xi\zeta^2.$$

By elimination of $\xi u, u, v, \zeta v, w$ there is reached in the same way a cubic of the same kind, alike even in the particular that all its terms involve η except

$$13467\xi^2\zeta, \quad 13469\xi\zeta^2.$$

The performance of subtraction thus enables us to divide by η and to arrive at an equation containing only the variables ζ^2, η^2, ζ^2, $\xi\eta$, $\eta\zeta$, $\zeta\xi$, namely, the equation

$$\begin{aligned}(-12467+13457)\xi^2+(-12568+23458)\eta^2+(-13569+23469)\zeta^2\\+(-12468+13458-12567+23457)\xi\eta\\+(-12569+23459-13568+23468)\eta\zeta\\+(-12469+13459-13567+23467)\zeta\xi=0.\end{aligned}$$

Similarly it is found that

$$\begin{aligned}(-14597+14678)\xi^2+(-24589+25678)\eta^2+(-34689+35679)\zeta^2\\+(-24579+24678-14589+15678)\xi\eta\\+(-34589+35678-24689+25679)\eta\zeta\\+(-34579+34678-14689+15679)\zeta\xi=0,\end{aligned}$$

and that

$$\begin{aligned}(-13478+12479)\xi^2+(-23578+12589)\eta^2+(-23679+13689)\zeta^2\\+(-13578+12579-23478+12489)\xi\eta\\+(-23678+12689-23579+13589)\eta\zeta\\+(-13678+12679-23479+13489)\zeta\xi=0.\end{aligned}$$

The final eliminant is thus a determinant of the 6th order, each of whose elements is either a five-line determinant or a sum of five-line determinants.

9. Almost all this work, however, is unnecessary, in view of the fact that the original set of equations is invariant to the simultaneous circular substitutions

$$\begin{matrix}\xi,\ \eta,\ \zeta=\eta,\ \zeta,\ \xi\ ; & \begin{matrix}1,\ 2,\ 3=2,\ 3,\ 1\ ;\\ 4,\ 5,\ 6=5,\ 6,\ 4\ ;\\ 7,\ 8,\ 9=8,\ 9,\ 7\ ;\end{matrix}\end{matrix}\qquad (S_1)$$

and also to the simultaneous circular substitutions

$$\begin{matrix}u,\ v,\ w=v,\ w,\ u\ ; & \begin{matrix}1,\ 4,\ 7=4,\ 7,\ 1\\ 2,\ 5,\ 8=5,\ 8,\ 2\\ 3,\ 6,\ 9=6,\ 9,\ 3.\end{matrix}\end{matrix}\qquad (S_2)$$

Making use of this invariance, we can construct the eliminant with ease as soon as two elements of the first row are known.

Thus, the first element of all being 12347, substitution S_1 gives 23158, 31269 for the next two elements of the first row: and the fourth element being the sum of the first two elements with columns 7 and 8 interchanged, the fifth element will be the sum of the second and third with columns 8 and 9 interchanged, and the sixth will be the sum of the third

and first with columns 9 and 7 interchanged. Then, having thus got the first element of every column, substitution S_2 suffices to give all the other elements; for example, the first element of the fourth column being

$$12348+12357,$$

the next two are

$$45672+45681 \quad \text{and} \quad 78915+78924:$$

and the fourth being the sum of the first and second with columns 3 and 6 interchanged, namely,

$$12648+12657+45372+45381,$$

it follows that the remaining two are

$$45972+45981+78615+78624,$$
$$78315+78324+12948+12957.$$

10. Further, since each of the given equations may be written in bipartite notation,

$$\begin{array}{ccc|c} \xi & \eta & \zeta & \\ \hline a_1 & a_2 & a_3 & u \\ a_4 & a_5 & a_6 & v \\ a_7 & a_8 & a_9 & w \end{array} = 0, \qquad \begin{array}{ccc|c} \xi & \eta & \zeta & \\ \hline b_1 & b_2 & b_3 & u \\ b_4 & b_5 & b_6 & v \\ b_7 & b_8 & b_9 & w \end{array} = 0, \quad \ldots;$$

and as each row of the eliminant consists of the coefficients of an equation in ξ^2, η^2, ζ^2, $\xi\eta$, $\eta\zeta$, $\zeta\xi$, and each column consists of the coefficients of an equation in u^2, v^2, w^2, uv, vw, wu, it would not be difficult to devise a rule for writing down any element of the eliminant quite independently of the others. Thus, the element in the (3,2)th place being the coefficient of η^2 in the one set of equations and of w^2 in the other set must have its column-numbers taken from the mutilated bipartite

$$\begin{array}{ccc|c} \xi & \eta & \zeta & \\ \hline . & 2 & . & u \\ . & 5 & . & v \\ 7 & 8 & 9 & w, \end{array}$$

and, as a matter of fact, it is 25789.

ON SOME METEOROLOGICAL CONDITIONS CONTROLLING NOCTURNAL RADIATION.*

By J. R. Sutton, Sc.D., Hon. Memb. R.Met.S., F.R.S.S.Af.

(Read March 20, 1912.)

Some observations made at Kimberley during a period of eight years with two radiation (spirit) thermometers, one placed upon the grass and the other mounted on a light brass stand 5 inches above the grass, gave the following monthly averages of minimum temperature :—

TABLE 1.

Minimum Radiation Temperatures.

	5 Inches above Grass.	On Grass.	D.
	°	°	°
Jan.	58·0 F.	55·0 F.	3·0 F.
Feb.	57·1	53·9	3·2
Mar.	53·6	50·9	2·7
April	45·0	41·5	3·5
May	37·5	32·8	4·7
June	31·2	25·5	5·7
July	30·6	24·2	6·4
Aug.	32·9	26·9	6·0
Sept.	41·6	36·5	5·1
Oct.....	45·5	40·9	4·6
Nov.	50·2	46·1	4·1
Dec.	55·1	51·8	3·3
Year	44·9	40·5	4·4

* This paper should be read in conjunction with a previous paper: J. R. Sutton, "The Influence of Water Vapour upon Nocturnal Radiation," in *Scientific Proc. R.D.S.*, August, 1905.

These results are to be regarded as approximately correct to the limits of accuracy of spirit thermometers. The readings of the thermometers are, if anything, rather higher than the truth on account of the sluggishness of the instruments; but a test of their performances as compared with mercurial thermometers has given no material support to Walter's claim that spirit thermometers are altogether unsatisfactory.* In any case the mean differences, D, are not likely to be widely different from what they would have been if mercurial thermometers had been used.

The differences between the minima, given in the Table, are not strictly comparable, because there is nothing to show that the minima registered by the two thermometers fall exactly at the same instant of time. It is, however, certain that the synchronous differences average high, especially in the winter months, when a value for D of 10° F. is by no means uncommon.

The interpretation of the numbers given in Table 1 is not at first sight very obvious. It can be seen upon following the run of the observations day by day that the results depend in some way upon the state of the sky and the moisture conditions of the atmosphere. On cloudy nights, that is to say, or on clear nights after rain, the radiation-temperature gradient, $K \cdot d\theta/dx$ say, measured upwards, will mostly be very small, and occasionally even reversed in sign. Yet, on the other hand, in cloudy and rainy weather considerable gradients are often observed.

Therefore, for the purpose of getting into a better position for the interpretation of the results of Table 1, a series of hourly observations of the simultaneous readings of the two thermometers between the times of sunset and midnight was commenced in May, 1910, and continued until August, 1911. The mean results for this piece of work are given in three sets in Tables 2, 3, 4, for the five hours 8 p.m. to midnight, *i.e.*—

1. Table 2, for very clouded skies in which the cloudiness exceeded 50 per cent. for the whole evening;
2. Table 3, for skies less than one-half obscured by cloud;
3. Table 4, for unclouded skies. In this case the refinement of distinguishing degrees of clearness was attempted but not carried out.

* A. Walter: "Discussion of the Errors of certain Types of Minimum Spirit Thermometers in use at the Royal Alfred Observatory, Mauritius" (*Trans. S.A. Phil. Soc.*, 1907).

TABLE 2.

Time.	D.	Cloud.	Dew-point.	Relative Humidity.	Wind.
	°	%	°	%	M. per H.
XX.	3·7 F.	82	46·3 F.	60·5	4·3
XXI.	3·4	86	46·0	62·2	4·7
XXII. ...	3·3	89	46·1	64·7	4·9
XXIII. ...	3·2	88	45·9	66·4	4·9
Midnight	3·1	78	45·8	68·3	4·8
Average...	3·3	85	46·0	64·4	4·7

TABLE 3.

Time.	D.	Cloud.	Dew-point.	Relative Humidity.	Wind.
	°	%	°	%	M. per H.
XX.	5·5 F.	32	43·4 F.	56·2	3·2
XXI.	5·4	27	43·2	59·3	3·0
XXII. ...	5·3	24	43·1	61·9	2·9
XXIII. ...	5·3	25	43·0	64·3	2·9
Midnight	5·1	23	43·0	67·0	3·0
Average...	5·3	26	43·1	61·7	3·0

TABLE 4.

Time.	D.	Cloud.	Dew-point.	Relative Humidity.	Wind.
	°	%	°	%	M. per H.
XX.	7·3 F.	—	36·9 F.	55·0	3·0
XXI	7·2	—	36·3	57·3	3·2
XXII. ...	7·0	—	35·7	59·1	3·3
XXIII. ...	6·8	—	35·5	60·9	3·5
Midnight	6·6	—	35·2	62·8	3·6
Average...	7·0	—	35·9	59·0	3·3

Upon the rare occasions when a single observation was missed during the evening, values were interpolated for that hour. If more than one observation was missed during an evening, that evening's observations were rejected altogether. Of the whole number of evenings in which a complete set of hourly observations was obtained, the seasonal distribution was as follows:—

	Summer.	Winter.	Total.
Very clouded nights ...	41	52	93 evenings
Clouded nights.....	42	43	85 ,,
Clear nights	46	144	190 ,,

From which it is manifest that a preponderance of winter observations has come in for the clear night results.

For our immediate purpose it may be sufficient to assume that the temperatures of the two thermometers are governed first by radiation of heat from the lower thermometer to space, and second by the conduction —evidently slow—of heat from the level of the upper thermometer to that of the lower. The actual circumstances are certainly much more complex, but they may be regarded as reducing to that, as a first approximation. On this assumption the greater the intensity of radiation the greater will be the fall of temperature of the lower thermometer below what it would otherwise have shown; but at the same time the fall of temperature of the upper thermometer will also be the greater since the temperature gradient is greater. A steady difference of temperature between the two thermometers will be attained when the flow of heat along the temperature gradient in the space between them is sufficient to counterbalance the radiation. It is the purpose of this investigation to discuss the meteorological conditions that determine the said steady difference.

The velocity of the wind cited in the last three Tables was measured by a Robinson Anemometer whose cups are 45 feet above the ground. On the ground itself the air movement will have been much less.

The given relative humidity is for the standard height of 4 feet, and clearly, therefore, if the aqueous vapour content of the lower air is fairly uniform, the relative humidity must be much greater near the cold surface of the ground than it is at a height of 4 feet. This is demonstrated by the fact that dew will often begin to form on the ground when the standard relative humidity is only 70 per cent.

In Table 5 is tabulated the number of times dew (or hoar-frost) was noted in the period, of 15 months or so, under review, corresponding to the state of the sky and the relative humidity.

TABLE 5.

FREQUENCY OF DEW.

Relative Humidity.	On Clear Nights.	On Cloudy Nights.		On Very Cloudy Nights.	
%	No.	No.	Cloud %.	No.	Cloud %.
90 and over...	39	20	29	26	82
85–89	42	32	22	9	80
80–84	46	29	24	6	65
75–79	47	19	14	3	67
70–74	57	6	3	5	100
65–69	33	2	10	2	95
60–64	8	—	—	4	83
	272	108	—	55	—

The above are hourly values. Thus of the whole number of nights considered, 190 were clear, and these comprised 950 separate hours of observation. Of these 950 hours 272 had dew. Again, out of 890 hours at which cloud was noted, 163 (= 108 + 55) had dew. Roughly speaking, 29 per cent. of the clear nights, 25 per cent. of the cloudy, and 12 per cent. of the very cloudy, had dew before midnight. On pretty well every clear night dew will be deposited as soon as the relative humidity at a height of 4 feet falls below 75 per cent.; and also on pretty well every moderately clouded night as soon as it falls below 80 per cent. There would, no doubt, be a greater number of dewy evenings noted under very clouded skies were it not that the rain often intervenes to mask it.

As might have been expected in accordance with current theories, the averages of Tables 2, 3, and 4, show that the radiation-temperature gradient is less as the sky is more clouded. But the quantity of water vapour in the air, and also the relative humidity, increase with increase of cloud. Hence, still following current theories, the quantity of water vapour might be regarded as contributing to the result. If, however, we examine these three Tables in detail we see that D gradually diminishes as the hour becomes later, the state of the sky, clouded or otherwise, apparently making very little difference in the rate of its decrease. Concurrently the vapour pressure—as indicated by the dew-point temperature—falls, though here this fall is greatest when the nights are clear; also the relative humidity increases, and, curiously enough, faster when the sky is less than one-half obscured; while the wind rises on the whole both when the sky is clear and when it is very clouded, remaining fairly constant for a small amount of cloud.

These facts suggest that next to the "blanketing" effect of the clouds the relative humidity more or less modified by the velocity of the wind is alone of importance in determining the radiation-temperature gradient. This point we now proceed to emphasise.

Table 6 shows for each percentage of relative humidity, in rising grades of 5 per cent. each, under clear skies:—

Col. 1. The grade of relative humidity;
2. The mean relative humidity of the grade;
3. The number of observations in the grade;
4. The corresponding mean differences of temperature between the two thermometers;
5. The corresponding values of the dew-point temperature; and
6. The corresponding mean velocity of the wind for the hour ending at the time of observation.

TABLE 6.

SUMMARY OF MEAN RESULTS UNDER CLEAR SKIES.

Relative Humidity.		No.	D.	Dew-point.	Wind.
Grade.	Mean.	Times.	F.	F.	M. per H.
%	%		°	°	
Under 30	26	24	8·3	37·9	4·6
30–34	32	49	7·3	37·9	4·8
35–39	37	58	7·8	36·6	3·6
40–44	42	66	7·2	33·0	3·9
45–49	47	78	6·9	33·5	4·5
50–54	52	110	7·0	35·1	4·3
55–59	57	111	7·1	35·2	3·6
60–64	62	103	7·5	34·4	3·0
65–69	67	98	7·6	35·1	2·6
70–74	72	76	7·1	36·1	2·2
75–79	77	50	5·8	38·3	2·7
80–89	84	88	5·5	39·1	1·9
90–100.....	92	39	5·9	40·5	1·5

Evidently the dew-point effect is slight at the best, if it can be said to have any existence at all. On the whole the temperature differences D fall as the relative humidity increases. But there is an important break in the regularity of the fall, and D shows a rise, instead of a fall, all the way from a mean relative humidity of 47 per cent. to 67 per cent. A reference to the column of wind velocities furnishes the explanation,

namely, that the rise in the value of the difference of temperature (where there should be a fall) is caused by a partial overriding of the relative-humidity effect by the varying velocity of the wind.

Table 7 supports this view. It gives for each grade of relative humidity the average temperature differences, smoothed in threes, corresponding to grades of two miles an hour in the wind. The first column contains the average value of the relative humidity; at the head of each column after the first is the velocity of the wind for that column.

TABLE 7.

RADIATION TEMPERATURE DIFFERENCES CORRESPONDING TO GRADES OF RELATIVE HUMIDITY AND WIND MOVEMENT.

Mean Relative Humidity.	Wind in Miles an Hour.					
	0-1·9.	2-3·9.	4-5·9.	6-7·9.	8-9·9.	10 & more.
%	°	°	°	°	°	°
92	6·1	5·7	4·2	—	—	—
84	6·2	5·5	4·4	2·7	—	—
77	6·7	5·9	5·0	4·1	5·0	—
72	7·4	6·9	5·6	4·4	5·0	—
67	7·8	7·5	6·3	3·7	5·0	4·5
62	7·8	7·8	6·8	3·9	4·1	4·0
57	7·6	8·0	6·9	4·6	4·3	3·8
52	7·4	7·9	7·0	5·8	4·3	4·0
47	7·5	7·9	6·9	6·1	5·2	4·1
42	7·8	7·7	7·2	7·2	6·0	4·1
37	8·1	8·0	7·4	7·4	5·9	4·3
30	8·3	8·5	7·7	7·2	5·2	5·0

Thus as the mean relative humidity falls from 92 per cent. to 30 per cent. the mean value of D rises from 6°·1 to 8°·3, while the velocity of the wind is between zero and 1·9 miles an hour; from 4°·2 to 7°·7 while the velocity is between 4 and 5·9 miles an hour; and so on. Again, examining the lines, we see that for any assigned relative humidity the values of D fall as the wind gains strength. For a mean wind velocity of 8 miles an hour or more the relative-humidity effect is practically lost.*

As a final test for any possible dew-point effect Table 8 has been constructed. It shows for each grade of relative humidity the temperature differences corresponding to rising grades of two degrees each

* The wind at Kimberley is gusty as a rule. Consequently its velocity for the hour preceding an observation cannot be expected to closely represent the wind factor at the time of observation.

TABLE 8.

RADIATION TEMPERATURE DIFFERENCES CORRESPONDING TO GRADES OF RELATIVE HUMIDITY AND DEW-POINT.

Relative Humidity.	Dew-point Temperature in Degrees Fahr.											
	Under 30°.	30°–31°·9.	32°–33°·9.	34°–35°·9.	36°–37°·9.	38°–39°·9.	40°–41°·9.	42°–43°·9.	44°–45°·9.	46°–47°·9.	48°–49°·9.	50° & more.
%	°	°	°	°	°	°	°	°	°	°	°	°
Under 30	—	9·8	10·4	9·6	—	6·4	5·9	10·0	7·4	—	—	—
30–34	7·1	5·9	8·1	6·1	6·1	7·7	6·6	7·9	9·0	—	—	—
35–39	8·6	7·7	6·4	8·6	8·1	8·2	7·5	7·1	8·5	8·7	6·9	—
40–44	8·1	7·1	6·9	7·4	7·6	7·0	5·3	4·5	5·2	6·4	—	—
45–49	7·9	7·5	8·2	6·3	6·6	6·6	5·8	5·8	3·9	4·1	3·8	6·4
50–54	8·1	8·1	8·2	7·0	7·3	6·6	5·0	4·6	4·8	5·5	5·2	—
55–59	8·2	8·9	8·0	6·4	5·7	6·8	4·9	5·0	5·8	5·6	6·0	—
60–64	9·0	8·9	7·6	7·8	5·6	6·9	6·6	6·0	4·4	5·1	5·8	—
65–69	8·1	8·9	8·9	8·1	7·7	6·3	7·5	6·0	—	4·4	4·2	4·4
70–74	7·3	7·8	7·3	8·2	7·1	6·8	7·0	6·1	5·7	3·4	4·3	5·2
75–70	6·2	5·6	5·3	6·6	6·8	6·3	6·7	6·4	6·3	3·3	6·2	4·0
80–89	6·2	5·3	5·6	6·9	5·0	5·7	6·1	6·1	5·4	4·3	5·5	2·8
90–100	7·3	—	—	6·0	6·4	6·5	6·8	4·5	5·6	4·3	—	2·9
Average	7·7	7·6	7·6	7·3	6·7	6·8	6·3	6·2	6·0	5·0	5·3	4·3

TABLE 9.

WIND VELOCITIES IN MILES AN HOUR CORRESPONDING TO GRADES OF RELATIVE HUMIDITY AND DEW-POINT.

Relative Humidity.	Dew-point Temperature in Degrees Fahr.											
	Under 30°.	30°–31°·9.	32°–33°·9.	34°–35°·9.	36°–37°·9.	38°–39°·9.	40°–41°·9.	42°–43°·9.	44°–45°·9.	46°–47°·9	48°–49°·9	50° & more.
%												
Under 30	—	2·7	4·2	6·4	4·6	4·8	5·1	5·1	1·5	—	—	—
30–34	7·5	8·0	3·6	4·3	5·0	4·2	6·0	4·3	1·6	—	—	—
35–39	4·6	3·6	5·9	2·0	2·7	1·5	3·8	4·0	2·0	2·4	1·0	—
40–44	3·3	4·6	5·0	3·3	2·0	2·2	6·0	8·0	3·4	4·2	—	—
45–49	3·7	4·7	3·0	4·9	5·5	2·5	5·0	3·0	6·9	4·7	10·5	8·2
50–54	3·3	3·0	4·6	3·9	4·9	5·7	6·0	8·1	2·9	1·0	5·9	—
55–59	2·5	1·8	3·0	3·8	6·9	4·0	5·3	7·6	3·3	3·0	2·2	—
60–64	2·0	2·9	2·7	2·4	6·5	4·2	5·1	2·4	1·1	3·3	—	—
65–69	2·3	1·1	1·5	2·4	3·1	4·2	2·7	2·3	—	2·5	5·0	3·2
70–74	1·8	1·9	2·5	2·0	2·2	1·9	2·5	2·7	1·0	2·8	2·7	2·9
75–79	3·5	3·3	3·8	2·5	1·2	1·7	1·7	2·5	1·9	2·6	3·4	3·5
80–89	0·5	1·9	0·8	1·8	2·5	1·7	1·0	0·5	3·0	3·5	1·5	4·9
90–100	0·0	—	—	1·4	2·0	1·2	0·2	2·5	2·1	2·5	—	1·2
Average	2·9	3·3	3·4	3·2	3·8	3·1	3·9	4·1	2·6	3·0	4·0	4·0

of dew-point temperature. Here it is to be observed that the dew-point numbers would be antecedently expected to exhibit a sort of illusory influence on the temperature differences of our two thermometers. For take any grade of relative humidity, say the one comprising 50 per cent. to 54 per cent. Granting that the temperature differences fall as the relative humidity rises, there would be a small fall of temperature difference inside the limits of the grade—the temperature difference being less for 54 per cent. than it is for 50 per cent. of relative humidity. But there would also be in general, at the same time, a rise of dew-point corresponding to the rise of relative humidity. The mean results at the foot of the Table show this illusory influence quite clearly. Yet even here, as we see from Table 9, which gives the corresponding velocities of the wind, a great part of the effect shown, such as it is, is due to the wind movement. After allowing for the gradual illusory fall of temperature difference running parallel with the rise of dew-point in each grade of relative humidity, it is evident that the irregularities in the mean values of Table 8 agree fairly well with the irregularities in the mean wind velocities; the maximum points in one Table opposing the minimum points of the other.

To summarise the results it appears that after allowance has been made for the state of the sky and the movement of the air, the only factor of real importance determining the magnitude of the radiation-temperature gradient is the relative humidity. The absolute humidity, as such, is unimportant. The non-recognition of the distinction between the two elements of humidity (granting, of course, the justice of my argument) has vitiated many of the so-called classical experiments in the domain of radiant energy: the experiments out of which the theory of the wet bulb thermometer has been manufactured, for instance. Or take the seemingly simple case—more simple at any rate than the meteorological problem—of the cooling of a hot ball in a closed room filled with atmospheric air. In dealing with this case the "laws" commonly cited are Newton's and (indirectly) Stefan's. But it must be evident that the relative humidity in the vicinity of the ball must be considerably greater at the beginning than it is at the end of the experiment when the temperature of the ball has fallen almost to that of the room. Hence on that account alone the radiation of heat will be relatively greater at the higher temperature. Probably not one single text-book has ever hinted that no such experiment can be valid unless it be performed in absolutely dry air; or, shall we say, unless due allowance be made for moisture conditions.

Moreover, these considerations seem to help towards explaining the discrepancies between the results obtained by those who have experimented upon the absorption of heat by aqueous vapour. Had Tyndall

passed the radiant energy from his source of heat through a given quantity of aqueous vapour (at a temperature maintained constant) confined, suppose, in a telescopic tube, he would, if my argument is sound, have found a greater or less effect upon the needle of his galvanometer according as the tube was lengthened or closed up; since the relative humidity would be less or greater as the tube was made longer or shorter, while the actual quantity of moisture would have been unaltered. Tyndall, as is known, ascribed his results solely to the pressure of the water vapour in the given absorbing space,* omitting to notice that the relative humidity was greater as the quantity of water vapour used was greater.

Again, Magnus† placed his source of heat in contact with his absorbing material, thus raising its temperature and lowering its relative humidity in the considerable interval that was allowed to elapse before the galvanometer needle attained to its "stationary" position.

Whenever dew begins to form, condensation invariably commences on the lower of the two thermometers. Because, therefore, of the latent heat liberated at the lower level, and because of the lesser radiation of water as compared with the ordinary solid matter of the earth's surface,‡ it might fairly be expected that the commencement of condensation in the form of dew would check the nocturnal cooling of the earth's surface, and hence that the radiation-temperature gradient in the space between the two thermometers would become less steep. For reasons now to be discussed, however, my observations show no easing of this gradient by dew. Throughout the whole period of observations there were 27 clear evenings in which dew began to form at some instant between XX. and midnight. [There were many other evenings in which dew was already formed at XX. o'clock, but these are not brought into account since the point to be tested was what reduction of the radiation took place when dew began to form.]

Now these 27 evenings of incipient dew show the following hourly gradients:—

XX.	XXI.	XXII.	XXIII.	Mid't.
6·9	6·8	6·6	6·3	6·4 degrees F.

* See, chiefly, his two memoirs contributed to the Royal Society in 1862: (1) "On the Absorption and Radiation of Heat by Gaseous Matter"; (2) "On the Relation of Radiant Heat to Aqueous Vapour." Poynting and Thomson (*Heat*, 1904, p. 236) take the very sanguine view that Tyndall's conclusion is "confirmed by the observations of meteorologists on the greater or slower rate of cooling of the earth at night when the air contains less or greater amounts of water vapour."

† *Phil. Mag.*, August, 1861.

‡ When dew is forming there is, moreover, no evaporation whereby the temperature of the wet surface can be lowered.

TABLE 10.

RADIATION TEMPERATURE GRADIENT AND CORRESPONDING WIND VELOCITY UPON EVENINGS OF INCIPIENT DEW.

		(1) Values of D.					Decrease of D at hour of Incipient Dew.	(2) Wind Velocity.					Increase of Wind Velocity at Hour of Incipient Dew.
		XX.	XXI.	XXII.	XXIII.	Mid't.		XIX.	XX.	XXI.	XXII.	XXIII.	Mid't.
		°	°	°	°	°	°						
May	25, 1910	9·2	8·3	**8·3**	7·7	7·9	0·0	0·2	1·4	**1·5**	2·8	2·7	+0·1
	29	7·8	**7·3**	6·7	7·1	5·3	+0·5	0·5	**0·1**	0·0	0·0	0·0	−0·4
	30	8·2	8·2	**7·3**	7·9	6·5	+0·9	2·9	1·9	**2·0**	1·6	1·2	+0·1
June	3	8·3	8·3	8·3	7·6	**8·8**	−1·2	2·2	2·6	2·4	2·4	**3·3**	+0·9
	13	6·5	6·4	4·8	**4·6**	5·1	+0·2	7·9	9·2	7·0	**5·4**	4·9	−1·6
	22	8·2	8·3	**8·3**	7·6	7·7	0·0	2·9	1·9	**0·9**	0·0	0·1	−1·0
	27	9·2	7·9	9·3	8·7	**9·6**	−0·9	1·7	1·0	1·6	0·9	**2·0**	+1·1
July	7	5·1	**3·6**	3·8	4·0	4·6	+1·5	6·8	**3·1**	2·4	4·6	5·3	−3·7
	10	7·1	6·8	6·6	**6·0**	6·1	+0·6	2·6	1·6	3·1	**1·7**	2·0	−1·4
	25	8·3	9·4	**9·6**	9·3	8·7	−0·2	3·0	1·8	**2·0**	3·8	3·0	+0·2
Aug.	1	4·8	4·7	5·2	**5·1**	5·0	+0·1	8·7	9·7	9·8	**6·5**	6·9	−3·3
Sept.	11	4·4	4·2	3·6	4·2	**4·3**	−0·1	6·1	8·3	9·4	5·0	**2·7**	−2·3
Oct.	3	2·3	3·3	3·4	1·8	**1·4**	+0·4	0·0	0·0	0·8	1·8	**1·4**	−0·4
Dec.	30	4·4	4·5	**4·5**	4·3	4·3	0·0	3·2	0·9	**1·8**	0·3	1·3	+0·9
Mar.	23, 1911	5·5	5·9	**6·3**	3·4	4·5	−0·4	3·0	3·4	**3·9**	2·8	1·3	+0·5
April	19	5·3	5·1	**5·4**	5·3	5·9	−0·3	3·1	3·5	**2·8**	2·0	2·8	−0·7
	20	6·1	6·3	6·3	**6·3**	6·8	0·0	3·9	2·2	1·4	**1·7**	2·3	+0·3
May	2	8·0	8·5	**8·8**	8·3	7·6	−0·3	5·1	4·7	**2·2**	1·7	1·3	−2·5
	31	8·4	8·5	7·3	7·3	**7·0**	+0·3	3·7	4·1	4·6	5·0	**5·5**	+0·5
June	20	9·3	8·9	**8·5**	9·7	9·6	+0·4	0·5	0·6	**0·4**	1·5	3·2	−0·2
	26	4·6	4·6	4·3	**5·4**	5·3	−1·1	6·8	5·8	7·7	**6·2**	6·1	−1·5
	30	8·5	**8·6**	7·8	8·4	8·3	−0·1	0·9	**2·0**	1·9	3·1	3·9	+1·1
July	2	9·4	8·6	**8·2**	7·5	7·8	+0·4	2·4	1·0	**1·0**	1·1	0·3	0·0
	3	8·6	9·6	7·8	8·1	**8·3**	−0·2	0·4	0·9	1·5	1·3	**0·7**	−0·6
	11	8·4	7·6	7·5	**6·8**	7·7	+0·7	—	—	—	—	—	?
Aug.	4	6·2	6·8	**6·7**	5·3	5·5	+0·1	3·3	3·4	**2·1**	2·0	4·1	−1·3
	10	3·5	**3·5**	3·9	3·3	2·5	0·0	5·3	**4·3**	3·8	3·7	3·2	−1·0

Excepting that this sequence is somewhat more irregular, perhaps on account of the small number of observations dealt with, it shows no such striking contrast to Table 4 as might have been anticipated. Of the 27 nights of incipient dew, twelve showed a diminution of the gradient from one hour to the next when dew had begun to form in the interval; ten showed an increase, while the remaining five showed no change at all. Both the diminution and the increase of the gradient averaged about 0·5 degree F.

But a partial if not complete explanation of this curious result is furnished by a comparison between the radiation-temperature gradients and the corresponding velocities of the wind. In the respective hours during which dew began to form on 26 evenings (the anemometer was out of action on one night of the 27), ten showed an increase of wind velocity as compared with the preceding hour, 15 showed a decrease, and in one case there was no change. The important point, however, is that the general tendency on these nights of incipient dew is for the wind velocity to decrease, *i.e.* :—

XIX.	XX.	XXI.	XXII.	XXIII.	Mid't.	
3·3	3·1	3·0	2·6	2·7		miles per hour.

Whereas, as we saw from Table 4, the tendency on clear nights generally is for the velocity to increase. Since, then, the velocity decreases instead of increasing, the radiation-temperature gradient should increase on this account (see Table 9). As it does not increase, but on the contrary decreases, it follows that the formation of dew does cause, or rather accompanies, a decrease of the gradient. Of course the slackening of the wind is responsible in many cases for the circumstance that any dew forms at all.

Table 10 gives details of the observations under this head. The respective quantities in heavier type show :—

1. The value of the temperature difference between the two thermometers at the hour when dew was first seen;
2. The velocity of the wind in the hour during which condensation began on the lower thermometer.

ON THE VARIATION IN THE VALUE OF THE ATMOSPHERIC ELECTRICAL POTENTIAL WITH THE ALTITUDE.

By W. A. Douglas Rudge, M.A.

(Read March 20, 1911.)

Observations taken during the past two years have convinced the writer that some sort of relation should exist between the value of the potential gradient due to the charge existing in the air and the altitude of the place of observation, and some account of this matter has already been published by him. With the object of obtaining further information, a journey was made in September last from Bloemfontein to Lourenço Marques via Johannesburg, and then from Johannesburg to Durban. In this way places of observation could be secured where the altitude varied from sea-level up to nearly 7,000 feet, and records were taken of the potential gradient at as many places as possible.

The apparatus used consisted of a "Wilson" pattern gold-leaf electrometer, furnished with a collecting-plate of brass coated with a radium preparation. This latter had been in use for some time and gave consistent results, but ionium would probably be a better material than radium to work with. The results may, however, be regarded as comparative rather than absolute, and tests of the efficiency of the plate at the beginning and end of the observations showed that it had not changed in its power of taking the potential of that layer of the atmosphere in which it happened to be. The electroscope was calibrated by a number of small storage cells used in conjunction with a sliding condenser, allowing potentials up to 500 volts to be measured. The electroscope was usually arranged so that the collecting plate was 140 cm. above the ground, but in some cases where the potential was high a less height was used. The movements of the gold leaf were observed by a reading microscope with a scale in the eyepiece. The gold leaf rapidly took up a fixed position (in a uniform field) and the double case of the instrument effectually eliminated any disturbance by the wind.

The start was made from Bloemfontein on September 24th. Between that place and Vereeniging there is not much change in level, and previous observations have shown that the potential gradient is fairly uniform. From Vereeniging to Johannesburg there is a rise of 1,000 feet, and this is accompanied by a decided fall in the potential gradient until Germistom is reached, and there, considerable fluctuations are noticed, especially if a strong wind is blowing. In Johannesburg the changes in the value of the gradient are so remarkable that they will be treated separately, and the general results from Johannesburg to Lourenço Marques and from Johannesburg to Durban taken first.

Johannesburg to Lourenço Marques.

After Johannesburg the first halt was made at Belfast, and here a day's observations were taken from 5.40 a.m. to 9.30 p.m. The country round Belfast is very open and free from trees, so that there were no circumstances to disturb the normal potential. The sky was practically free from cloud all day and the potential gradient appeared to follow the normal course, save that the second maximum occurred at 5 p.m. instead of about 8 to 9 p.m. By "normal" course is meant that the potential rises after sunrise up to a maximum value about 8 p.m., then falls to a minimum and remains constant for several hours, then rises to a second maximum which is lower than the first, and then falls to another minimum, until just before sunrise on the following day.

Table I. shows the values of the potential gradient in volts per metre at various times during the day.

Table I.

Belfast, 6,500 *feet.*

Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.
5.40 a.m.	30	8.30	48	1.15	20	5.45	50
5.50	36	9.0	48	1.30	20	6.0	48
6.0	40	9.30	46	2.0	25	6.10	30
6.5	42	10.0	46	2.30	33	6.20	27
6.10	46	10.35	43	2.35	36	7.0	23
6.20	48	11.0	40	2.50	40	7.15	18
6.30	50	11.30	35	3.0	42	7.30	25
6.47	54	11·45	28	3.25	45	7.45	25
7.0	56	12.0	22	3.45	45	8.0	28
7.15	58	12.15 p.m.	18	4.0	50	8.30	28
7.30	58	12.20	20	4.40	60	8.45	26
7.35	58	12.30	20	4.50	70	9.0	20
7.50	56	12.45	20	5.0	80	9.15	20
8·0	48	1.0	20	5.25	57	9.30	20

On the following day observations from 5.10 a.m. to 7.30 p.m. gave practically the same readings as those recorded in the Table.

From Belfast to Lourenço Marques observations were taken as opportunity offered during the stoppage of the train, but unless a clear space some distance to windward from the engine could be found the results were valueless. It has been shown in previous papers* how the steam from an engine affects the potential gradient.

The best values are those given in Table II., which were observed during long stoppages of the train.

TABLE II.

Belfast to Lourenço Marques.

	Time.	Altitude.	Pot. Grad.
Belfast	7.30 a.m.	6,500	58
Machadodorp	8.5	5,279	90
Waterval Boden	8.30	4,826	100
Waterval Onder	9.0	4,144	110
Sycamore	9.20	3,841	140
Elandshoek	10.29	2,930	150
Cairn	11.0	2,410	180
Nelspruit	11.40	2,349	200
Crocodile Poort	12.20 p.m.	1,827	210
Kapmuiden	12.50	1,342	250
Koomati Poort	2.50	619	300
Lourenço Marques	4.35	0	500

A progressive increase in the potential gradient is seen as the altitude diminishes. The numbers given are not those actually observed, but numbers calculated as follows:—

In order to compare the potential gradient at one place with that at another, the times of observation should be the same, or rather corresponding points on the daily curve should be taken. This, of course, would have necessitated a stop of one day at each place, and as this was impossible the following method was used, which, although obviously inaccurate, will not be very far from the truth. The relation between the maximum value of the potential gradient and the minimum value, is, for Bloemfontein as 4 : 1, for Pretoria 4 : 1, Belfast 4·5 : 1, Lourenço Marques 5 : 1 for the morning observation, and rather less for the afternoon. As an approximation the minimum may be taken as occurring at

* *South African Journal of Science*, February, 1912.

12 noon. The Table attempts to show what the maximum value would be at the place of observation. Straight lines were drawn upon squared paper from the value of the gradient at its maximum to that of the value at its minimum, the horizontal line being the axis of time, and then assuming that the potential falls with the time, values of the maximum gradient can be found by extrapolation. For example, an observation at Crocodile Poort at 11 a.m. gave a gradient of 110 volts per metre, but by extrapolation it is assumed that the maximum value of the potential gradient would be 210. Proceeding in this fashion, the values given in the Table have been deduced, but they must be taken as approximate only. The values of Belfast and Lourenço Marques are of course definite.

At Lourenço Marques two and a half days' observations were taken, partly at the Observatory, on the beach, and at points in the neighbourhood. The humidity of the air was very great, which interfered with the first half-day's and also the next day's work, but the third day, after 9 a.m., was drier, and gave what may be regarded as a normal set of observations.

A day's results, taken at the Observatory, are given in Table III.

TABLE III.

Lourenço Marques, September 27th.

Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.
5.30 a.m.	60	9.40	174	5.40	100
5.40	60	9.45	174	6.10	100
5.50	60	10.0	162	6.30	120
5.57	68	10.15	125	7.0	176
6.0	68	10.30	118	7.15	180
6.10	68	10.40	108	7.30	180
6.20	80	11.0	108	7.45	180
6.30	75	11.10	95	8.0	165
6.35	100	11.30	95	8.15	160
6.40	104	11.55	95	8.30	150
6.50	162	12.0	95	8.45	110
7.5	260	12.30 p.m.	95	9.0	100
7.17	280			9.15	87
7.35	280			9.30	87
7.40	158			9.45	90
7.50	225				
8.0	200				
8.10	280				
8.20	260				
8.30	196	5·25	100		

The course followed by the potential gradient is thus of the normal kind, but the value of the maximum is much less than the previous half-day's work would have led one to expect. The atmosphere was steamy and probably interfered with the efficiency of the radium collecting-plate. From 12.30 p.m. to 5.30 p.m. the gradient was practically constant.

On the following morning there was a "Scotch" mist, which made observations valueless until 8.30 a.m., when the mist cleared away and for the rest of the day the indications were normal. Considerable wind in gusts was blowing up to 8.30, and dust might have been caught up, thus diminishing the positive charge in the air.

TABLE IV.

Lourenço Marques, September 28th.

Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.
5.50 a.m.	30	6.40	30	7.45	30
6.0	0	6.50	30	8.0	0
6.5	35	7.0	45	8.30	60
6.10	30	7.15	48	8.45	100
6.12	0	7.30	110		
6.15	60	7.35	62		
6.20	80	7.40	60		
6.30	30				
		After mist had cleared away			
9.30	400	11.0	310	12.0	250
9.45	382	11.5	330	12.15 p.m.	205
10.0	360	11.15	335	12.30	260
10.15	310	11.30	300	12.45	250
10.30	310	11.40	300		
10.45	320	11.50	250		

JOHANNESBURG TO DURBAN.

On the down journey observations could not be taken on account of rain until Pietermaritzburg was reached, and then between 6 p.m. and 10 p.m. a maximum potential gradient of about 200 volts per metre was obtained, but as rain was falling in the neighbourhood the observation was not of much value.

Next day observations taken on a clear open space at the south end of the town gave the results shown in Table V.

TABLE V.

Pietermaritzburg, October 1st.

Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.
5.30	100	6.10	140	7.0	160
5.40	114	6.20	120	7.15	188
5.50	108	6.30	120	7.30	205
5.55	120	6.40	135	7.45	230
6.0	135	6.50	140	8.0	260

Pietermaritzburg is 2,200 feet above the sea-level and lies in a hollow, the hills rising to over 5,000 feet. From Pietermaritzburg a journey was made to Howick, 3,440 feet above sea-level. This was reached at 10 a.m. At Howick there is a waterfall on the Umgeni River, which drops sheer down for 360 feet, and gives rise to a considerable cloud of spray, and this, as anticipated, from comparison with the Victoria Falls, was the seat of a large amount of negative electrification. The fall is about 2½ miles from the railway station, and observations were taken as nearly as possible along the straight line joining the station and the fall. At about 2 miles from the fall the gradient was 200 volts per metre, and steadily diminished as the fall was approached. The electrification was of course positive in sign. At 350 yards from the fall the electrification was *zero*, and on getting nearer the fall the potential rose rapidly, reaching a very high *negative* value, probably 2,000 volts per metre, at the edge of the chasm. The shape of the gorge enables one to take observations for more than half of a circle round the fall as a centre, and also at Stockdale on the side opposite to the fall.

During the observation a distant thunderstorm was raging, and when the electroscope was on the zero line each flash was accompanied by a sudden rise in the potential to +60 volts, but on a little rain falling the potential rose to a higher negative value.

Between Pietermaritzburg and Durban observations were prevented by rain. At Durban the potential was very high even during the afternoon, and at 7 p.m. reached the value of about 350 volts per mile on the beach, and close to the dock over 400; the high value at the latter place being due to the clouds of steam emitted by several vessels in the port.

The following morning a rapid journey was made from Umbilo to Umgeni via Durban, between the hours of 7.30 and 8 a.m. These places are at practically sea-level, but are a little way inland, and the object was to ascertain whether the potential gradient was constant over a distance

of above 8 miles. The potential varied from 400 to 500 volts per metre, and, making allowance for trees, was practically constant. Observations were taken on the beach facing the Indian Ocean. A strong wind was blowing at the time, and considerable fluctuations were noticed and found to be due to the sand blown by the wind. Standing in the water the positive potential gradient was about 500 volts per metre, but this fell on walking in the direction the wind was blowing to 140, and rose again on passing beyond the range of the blown sand.

The maximum value of the potential gradient was 500 volts per metre, and the minimum a little under 300. The range is thus smaller than usually found, but this may have been due to the mist, which was present most of the day.

On the return journey to Johannesburg observations were taken at the places given in Table VI.; the values of the potential gradients are those actually observed. At times mist was present. The values are of quite a different order from those recorded for Durban, Pietermaritzburg, or Lourenço Marques.

Observations taken between Pietermaritzburg and Johannesburg give the following:—

TABLE VI.

October 4th.

	Altitude.	Time.	Pot. Grad.
Glencoe	4,320	6.0 a.m.	60
Dannhause	4,429	—	55
Newcastle	3,893	7.30 ,,	90
Boscobello	4,414	8.35 ,,	60
Inkwilo	4,554	8.50 ,,	48
Mount Prospect	4,983	9.10 ,,	45
Majuba	5,225	9.30 ,,	45
Charles Town	5,386	—	40
Volksrust	5,429	10.0 ,,	45
Zand Spruit	5,413	10.29 ,,	37
Paardekop	5,652	11.10 ,,	35
Standerton	5,022	12.40 p.m.	50
Val	5,160	1.50 ,,	50
Balfour	5,275	3.0 ,,	40
Heidelburg	5,026	4.0 ,,	40
Nigel	5,041	4.20 ,,	40

These values do not indicate much, and owing to the different times at which they were taken the results are not comparable, but they show a very marked difference from those taken at sea-level and at Maritzburg.

Observations at Johannesburg.

In July, 1911, some casual observations were taken of the potential gradients at Johannesburg and the value found to be much higher than that at Pretoria and Vereeniging, places about 45 miles from Johannesburg, and at a lower altitude, and also some considerable variations were observed in the values at different points outside the town. Very large quantities of steam and smoke are emitted from the engines at the mines, and these must have some influence upon the potential of the air in the neighbourhood. Another factor which has to be taken into account is the cloud of fine dust which rises from the mine heap during the process of "tipping" and also caught up by the wind. Steam gives to air a positive charge, whilst dust gives a negative.

Observations were begun at the Observatory on September 25th at 5 a.m. and continued until a steady value appeared to be reached, and the results are given in Table VII.

Table VII.

Johannesburg, September 25th.

Time.	Pot. Grad.	Time.	Pot. Grad.	Time.	Pot. Grad.
5.0 a.m.	60	6·25 a.m.	100	7.55 a.m.	160
5.10	66	6.30	100	8.0	180
5.12	70	6.40	105	8.20	150
5.30	75	6.50	115	8.30	100
5.45	80	7.0	125	8.40	155
6.0	80	7.10	150	9.0	155
6.10	98	7.15	160	9.20	160
6.17	95	7.20	168	9.30	160
6.20	95	7.30	168	9.45	180
				10.0	168
				10.20	168
				↓	
				11.40	160

It may be seen that the variation is not so great as that observed in the open country or in such places as Bloemfontein or Lourenço Marques.

At 10.20 a journey was made to Norwood, about 3 miles to the north of the Observatory, and the gradient taken there. Its value was only *52*, and on returning to the Observatory the value there was 160, and kept at

this for half an hour. The wind was blowing strongly from Norwood to Johannesburg.

From the Observatory to the centre of the town the gradient diminished, reaching a zero value in Joubert Park. On the roof of the School of Mines it was + 85 at 1 p.m., but, as this place is near to the railway station, every passing train caused the value to change rapidly.

Passing to the south side of the town, an open space is reached just before the Village Deep Mine, and observations taken in this neighbourhood showed surprising changes in the magnitude and sign of the electrification. A strong wind was blowing from the north at the time, and standing to the north of the mine the potential gradient was about +40. From the mine heap at the south end of the mine a large cloud of dust was being blown, and taking an observation at this end the magnitude of the potential gradient was *300* to *400* and *negative*. This abnormal electrification persisted for a considerable distance and was more than 150 volts per metre at a mile and a half away and still negative.

Inside the mine enclosure the electrification was positive close to the engines, zero in some places, negative at the beginning of the mine heap, the magnitude of the negative charge increasing as the heap was ascended. The same thing was seen near to other mines.

At the School of Mines the potential gradient was +120 at 4.30 and at the Observatory +160 at 6.30.

The general electrical conditions about Johannesburg are thus very abnormal as compared with other places in South Africa, and the cause is clearly due to the steam and dust.

On returning from Lourenço Marques on September 30th, the observations were repeated, but with very different results. There was no tipping of the sand going on, and very little wind, with the consequence that the electrification was everywhere *positive*, and also of high value. At the School of Mines the value was +200 at 10 a.m., and +250 at the Observatory at 4 p.m. On returning from Durban on October 5th the conditions were the same as on September 24th, viz., positive to the north, negative to the south of the town, with very high value near to the mine heap, from which clouds of dust were rising. The general results of the Johannesburg observations show to what a great extent the potential gradient in the atmosphere is influenced by steam and dust, and also that the influence is a local one. The various factors which influence the electrification of the atmosphere have been considered in a communication made to the *South African Journal of Science*.* An extended series of observations on the electrification caused by raising clouds of dust is now in progress, and will be published shortly.

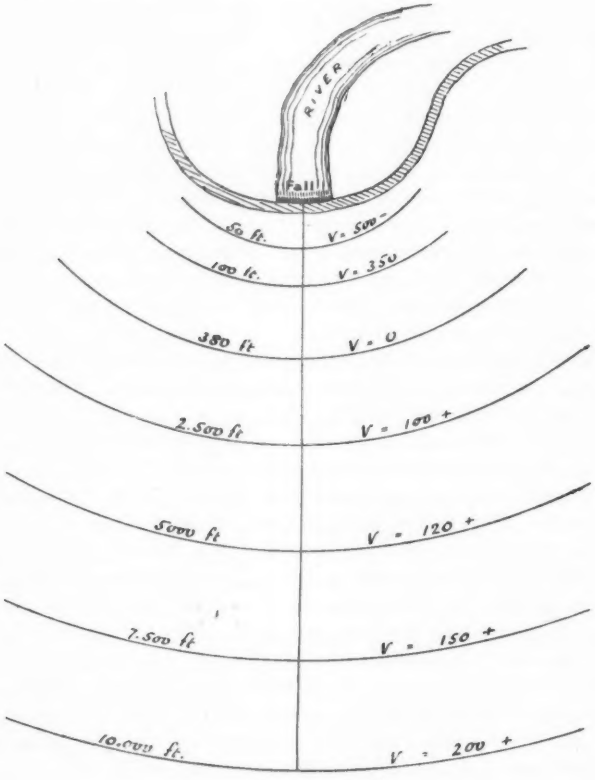
* March, 1912.

SUMMARY.

1. The potential gradient due to the normal electrification of the atmosphere varies inversely with the altitude, but the observations taken do not show any proportionality.

2. The daily variation in the value of the gradient follows the same course in places at high or low altitudes, save in the case of Johannesburg.

3. The variations at Johannesburg are due to the presence of steam and dust from the mines.



RESPIRATION AND CELL ENERGY.

By Horace A. Wager, A.R.C.S.

(Read March 20, 1911.)

It has been known for a long time that a supply of free oxygen is necessary for the carrying on of the vital processes connected with living protoplasm whether of plants or animals. A lack of oxygen means suffocation and eventually death for all living organisms. Protoplasm is a substance of proteid nature endowed with the mysterious property of vitality. Every organism, whether plant or animal, consists of either a single particle of protoplasm, or of a more or less complex body made up of a large number of such particles called cells. The vitality of the protoplasm is now supposed to be connected with a continuous state of internal molecular activity which appears to be a concomitant of all living protoplasm. The continuance of this molecular activity, and therefore the vitality of all living cells, is more or less dependent on the presence in the surrounding medium of free oxygen, but oxygen is not the cause of this activity. That is a property innate in the living protoplasm itself or due to its peculiar chemical composition. Oxygen cannot produce those movements of the atoms which are peculiar to living protoplasm of either plants or animals, as it is impossible to resuscitate dead protoplasm by a supply of oxygen. This molecular activity consists of the decomposition of the protoplasm together with the decomposition of the food substances in the cell and the reconstruction of the protoplasm and the building up of compounds required in the structure and well-being of the cell. This whole process is known as metabolism, the decomposition being distinguished as katabolism, and the building up as anabolism. The elements chiefly concerned in these processes are Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Phosphorus, which are supplied to plants in the form of various compounds, mostly in solution. The reconstructed compounds of the cell contain these elements in slightly different proportions from those found before decomposition, so that there results a

certain amount of waste. Plants have marked powers of reconstruction in the cell, and therefore their metabolism is not connected with any such excretion of waste (chiefly urea) as is found in higher animals. The chief waste materials are Carbon and Hydrogen, which are oxidised by the atmospheric oxygen, under the influence of the protoplasm, into Carbon-dioxide and water. These waste products are removed from the vicinity of the cell concerned. There is thus instituted in each living cell an interchange of gases, *i.e.*, oxygen is introduced into the cell, and waste products, usually in the form of gases, are removed from it. This process, which includes both these, is known as respiration. Without a sufficient supply of food in the cell the molecular activity of the protoplasm would result in the diminution of the protoplasm, and eventually death. Food material is rapidly used up, and as waste goes on conjointly, the result is, of course, a loss of weight unless the food supply is replenished. That there is such a loss in weight can be demonstrated in the following way. If some seeds are germinated for a few days in darkness it will be found that the total dry weight of the young plants will be less than the dry weight of the seeds (or control seeds) from which they grew. In fact the greater part of the food supplied to living cells is, as it were, wasted. Thus it has been calculated that the dry weight of a mould fungus is not greater than one-third to one-tenth of the organic food consumed. In mature animals the amount of food consumed does not increase the body weight, as the weight remains practically constant. A plant, however, is continually increasing in weight throughout its whole life.

The nutritive substances required by the living cells of plants are some carbohydrate (usually sugar) and water with mineral substances in solution. Proteid material may also be a nutritive substance, but it is doubtful if proteids are supplied to growing cells. Proteids are probably manufactured in all living cells from the carbohydrate and aqueous solutions supplied to them. The carbohydrate itself is produced on the plant in the green tissues as an additional product in the metabolism of the cell, in which the protoplasm uses different compounds from those used in colourless cells. This additional metabolism, to which the name photo-synthesis has been given, involves the combined action of the living protoplasm, light and chlorophyll, by which carbon-dioxide from the air and water are probably first decomposed and then reconstructed into the carbohydrate, the waste products of the whole metabolism being oxygen, and presumably, carbon-dioxide. During the light the carbon-dioxide given off, as well as that of the air, can be absorbed by the cell with oxygen and carbon-dioxide as the end products, but as light fails the carbon-dioxide is not absorbed but passes off, whilst the evolution of oxygen ceases. With the first rays of light some carbon-dioxide is absorbed and the different metabolism commences. In the absence of light or chlorophyll, or both,

carbon-dioxide is not available in metabolism, and metabolism is continued without it, that is, without the formation of a carbohydrate and with the end product of carbon-dioxide. It is difficult to imagine that photosynthesis is a separate and distinct process carried on by the protoplasm in addition to its ordinary metabolism. The exact function of the chlorophyll is not known, but it must be noted that chlorophyll and light are secondary factors in the metabolism. The prime factor is undoubtedly the living protoplasm whose own metabolism is included in that of the whole cell.

The first aim of the green cells is to make food for themselves and then to form an excess for translocation to other parts of the plant where required. Some of the excess may be stored away in different organs for future use. The formation of an excess has become a necessity in all complex plants. In fact this must have been one of the first steps in the differentiation of plant tissues—cells set apart for different purposes must have food supplied to them. In plants like Spirogyra each cell makes its own carbohydrate with very little excess. It has been calculated that in a laurel leaf the amount of carbohydrate formed in any given time is about thirty times as great as that required in the nutrition of the leaf cells. Also in a sunflower it has been found that 25 grams of starch are produced on a summer day on a square metre of leaf surface. A large amount of such carbohydrate is stored away in the seeds, &c., of the plants concerned for future use.

It is generally held that respiration is a distinct process involving changes taking place in a cell on account of the introduction of oxygen and such phrases as "respiratory material," "respiratory changes," and "respiratory organs" are in common use. Now oxygen is required in the ordinary metabolism of the protoplasm, and respiration cannot be considered as being a process apart from metabolism. In this paper respiration will be held to be simply the interchange of gases; that is, the introduction of oxygen to a cell and the removal of carbon-dioxide from it, the other processes being considered as connected with the nutrition and well-being of the cell.

Continuous metabolism is a prime property of all living protoplasm. It is present to a slight extent in the cells of resting bulbs, tubers, &c., and it is doubtful if it is entirely absent from the living cells of dry seeds and desiccated plants. The peculiarity of metabolism lies in the fact that decompositions and combinations go on in living cells which would not go on at ordinary temperatures outside the cell. Oxygen, &c., only operates on the substances in the cell when conveyed to them by the living protoplasm. The chemical actions, therefore, which take place in a living cell may be termed animate as compared with those that take place in dead matter, and which may be termed inanimate. The protoplasm

has wonderful regulative power. Two plants grown under the same conditions of light, chlorophyll, &c., may produce quite different carbohydrates, whilst the number of proteid substances already known is very great.

This metabolism, of course, requires a large amount of energy. It is usually stated that all the energy required by living cells has been obtained primarily from the sun's rays, *i.e.*, Pfeffer's "Physiology of Plants," vol. i., p. 297: "Both animals and plants derive their energy either directly or indirectly from the sun's rays which are converted into chemical energy by the agency of the chlorophyll apparatus. When a piece of coal is burnt a portion of the sun's radiant energy is liberated which was stored up in the form of potential energy many years ago, so that every steam engine is directly or indirectly driven by the sun." The whole of this statement I hope to show to be altogether erroneous. Energy may be defined as the amount of heat given out by a substance on being burnt or oxidised; that is, in all combinations of oxygen with other substances heat is usually liberated, especially in any combinations with carbon compounds. Heat or energy is measured in units called calories. A calorie is the amount of heat required to raise one gram of water through one degree Centigrade. In seeking for the energy available for the metabolism of the protoplasm two kinds of cells have to be considered —green cells and colourless cells. In green cells carbon-dioxide, water, and the protoplasm itself are being continually decomposed, with reconstruction chiefly of some carbohydrate. Now in order to break down a substance such as carbon-dioxide energy is required. The protoplasm, by the agency of the chlorophyll, undoubtedly makes use of the sun's rays to effect this. The energy required to break down a molecule of carbon-dioxide is the same as that given out when a carbon atom is burnt. This energy has been calculated in calories and may be represented in the chemical equation thus:—

$$C + O_2 = CO_2 + 97{,}000 \text{ cal.}$$

This is a gram-molecule equation and means that when 12 grams of carbon unite with 32 grams of oxygen, 44 grams of carbon-dioxide are produced with the liberation of 97,000 units of heat. Or again, if about half a milligram of carbon is burnt, one cubic centimetre of carbon-dioxide is formed with the liberation of about 4 units of heat. A similar equation for the formation of water is:—

$$H_2 + O = H_2O + 68{,}400 \text{ cal.}$$

The reverse of such an equation is true; that is, 68,400 calories are required to decompose a gram-molecule of water. It is usually stated that plants are enabled by the processes going on in their leaves to store

up energy for use in other parts of the plant. Thus a heap of coal is often pointed out as containing an enormous store of energy. Now before coal can be used as a source of energy it requires an even greater amount of oxygen to combine with it; that is, 12 tons of coal require about 32 tons of oxygen to unite with it in order to burn it up. Does the energy or heat given out come from the oxygen or the coal? It cannot be said to come from either. It is from the chemical union of the two, in which process heat happens to be given out. Carbon will give out heat when burnt, whether it is in the form of coal, charcoal, or diamond. Should it be said that the heat given out by burning a diamond has been obtained from the sun? No units of heat can therefore be assigned to the carbon atom or any other atom. Atoms and molecules undoubtedly contain heat or energy, but this can only be given out by the union of two or more of them, and in some cases more heat is actually absorbed into such atoms during the chemical union. When oxygen unites with carbon more heat is given out than when oxygen unites with hydrogen, as seen in the above equations. Atoms and molecules when heated contain more energy, and it is for this reason that many substances require heating before chemical union can be brought about. No substance, therefore, can be considered as containing energy, but a substance may represent available energy by virtue of its power of combining with other chemical substances, but even then it cannot be foretold whether heat will be given out or absorbed.

The question arises, are carbon-dioxide and water decomposed in the leaves before they are reconstructed into a carbohydrate such as sugar, or are they elaborated as carbon-dioxide and water? If not, it is difficult to imagine for what purpose the energy of the sun's rays is required. Light is certainly necessary to all green plants, and it is more than probable that it gives the necessary impetus to the protoplasm to perform these decompositions. It must be noted that protoplasm has the power of performing other decompositions without the presence of light. The first product of the leaf metabolism is supposed to be sugar. In any case it is probably in the form of sugar that it leaves the cell. In the formation of sugar heat is given out as represented in the following equation :—

$$6CO_2 + 6H_2O + 315{,}000 \text{ cal.} = C_6H_{12}O_6 + 6O_2,$$

but allowing that the carbon-dioxide and water have been decomposed, it may be convenient to represent the equation thus :—

$$6C + 6O_2 + 6H_2 + 6O + 315{,}000 \text{ cal.} = C_6H_{12}O_6 + 6O_2,$$

all the carbon being used up and some of the oxygen liberated. The sun's radiant energy is thus used only to bring about certain decompositions. In building up the sugar molecule from the elements energy is given out. The energy involved in the transformation of sugar into starch and back

again into sugar need not be considered.) Some of the energy thus liberated is available for metabolism, *i.e.*, to bring about further decompositions of substances in the cell or of the protoplasm itself. During the reconstruction of compounds in the cell some energy would again be given out, so that the final result of the whole metabolism of any living cell is a liberation of heat or energy. A substance like sugar therefore does not contain a store of energy, but energy is required to break it up before it can be used in the anabolic processes of the cell.

In colourless cells the metabolism also involves the using up and liberation of energy. As shown above, it cannot be stated that protoplasm is endowed with a supply of energy, and yet before any decomposition commences, say in germinating seeds, some energy must be available. The prevailing idea is that the protoplasm, as it were, wakes up and immediately goes to some store of energy in the cell, but as already pointed out, there can be no store of energy in a cell. There can be no energy available until some chemical union has taken place, *i.e.*, energy is usually liberated in the building up of compounds from elements and simpler compounds, especially in the case of plant compounds. It is probable that in this connection water, without which germination is impossible, plays a more important part than is usually attributed to it. The presence of water in germinating seeds may cause some chemical combination between the water and some substance in the cell or the protoplasm itself. The energy thus liberated would probably be sufficient to start the decomposition of other substances in the cell, say starch, and thus the metabolic processes would commence and so continue. The energy required in the decomposition of starch may be represented in the chemical equation thus :—

$$C_6H_{10}O_5 = 6CO_2 + 6H_2O + 365{,}000 \text{ cal.}$$

Ferments, enzymes, &c., need not be here considered as factors in the metabolism of the cell, as their actions are more or less bound up with the vitality of the protoplasm. In any case they have first to be manufactured by the protoplasm. Now oxygen as well as water is necessary to start the metabolism of the cell, and it may be that oxygen does the same thing as suggested above for water, that is, by entering into some chemical union with the protoplasm set free the first available energy. If that were so it is not apparent why the continued presence of oxygen should be necessary, or for that matter water, but water is probably used mechanically in growth as well as for the constructive processes of the protoplasm. It has been demonstrated in the case of the frog that it is not only able to live for some time in an atmosphere devoid of oxygen, but that it will even continue to exhale carbon-dioxide. Similar demonstrations can be made in the case of plants. Under such circumstances it is

evident that the oxygen must be derived from the decomposition of the organic substances in the cell. Pfeffer, however, states that oxygen is not primarily set free, but that the carbon-dioxide evolved is the end product of such abnormal decomposition. This form of respiration is called intramolecular respiration, but, if Pfeffer's statement is true, then the process is not one of respiration at all, since oxygen as oxygen is not involved. In any case it must be noted that during such conditions all growth ceases and abnormal processes of decomposition take place, whereby alcohol and other products are formed, until the accumulation of such injurious products is sufficient to kill the organism. If oxygen, however, is readmitted early enough ordinary respiration may be re-established and the organism will survive. It has been estimated that a plant will use up about 50 per cent. of its substance before death ensues. This helps to show that free atmospheric oxygen is not necessary to carry on the decomposition processes of nutrition. Some of the lower plants amongst the Bacteria and Fungi are able, under favourable conditions, to exist for a long time without free oxygen. This capability goes so far in some Bacteria that no trace of free oxygen is even necessary for their existence, whilst some cannot even live in the presence of oxygen. Such organisms are called Anaerobes to distinguish them from Aerobes. Concerning the carbon-dioxide evolved the question arises, is carbon-dioxide given off primarily in the form of carbon-dioxide, or is it only carbon that is given off? In the metabolism of the cell, substances are first decomposed and then reconstruction takes place. Most of the components of the decomposed materials are used up, especially in plants, but it would appear that there is a residual amount of carbon which is either a true residuum or carbon in a condition which cannot be utilised. If this carbon is not removed it may be that it would interrupt the chemical actions in the cell. In any case the carbon is oxidised into carbon-monoxide and then into carbon-dioxide and carried off as a gas. This oxidation liberates more energy which is available by the protoplasm, and in my opinion this is the chief source of energy of all living protoplasm. Plants go to considerable trouble to get the small amount of carbon-dioxide present in the atmosphere, and yet in the metabolism of the cell it is given up again most readily. Thus a plant sacrifices a large proportion of its food in order to obtain the energy necessary in metabolism. Carbon is therefore probably set free by the protoplasm for the definite purpose of uniting with oxygen and thus supplying energy. A supply of free oxygen has thus become a necessity to all living cells. It has been calculated that a seedling poppy plant whose dry weight was about half a gram gave off 55 cubic centimetres of carbon-dioxide in 24 hours, thus liberating 220 units of heat. This heat is sufficient to raise 22 grams of water through 10 degrees Centigrade. All this energy is not used up in the

metabolism of the cell, as the result of the sum of all the metabolic processes is always an evolution of heat, which is, of course, easily apparent in the bodies of higher animals. Also in some plants under certain conditions the evolution of heat can be demonstrated. The excess of heat in plants is probably used up to further transpiration, especially in the green parts of plants. Transpiration, which is a form of evaporation, requires heat, and probably in the ordinary way water would not evaporate quickly enough for the plant's needs. It is hardly likely that any radiation of heat takes place from leaves, as leaves are usually at a slightly lower temperature than the surrounding atmosphere, so that instead of leaves giving out heat they would be more likely to absorb it. Some of the excess energy may be used to produce the osmotic forces manifest in cells, or again some may be used to prepare the dissociated atoms of katabolism for chemical union.

In animals the food consists of already combined organic compounds, and the metabolism of animal cells may therefore be compared with that taking place in colourless vegetable cells—the metabolism in both cases being based upon chemical changes involving a liberation and redistribution of energy.

Whether the energy present in atoms and molecules comes originally from the sun is not the point under consideration in this paper. I have endeavoured to establish the new theory that the energy of the sun's rays is not used either directly or indirectly in the metabolism, say of a germinating seed. It is the energy present in atoms and molecules which is released by some chemical union that is available in cell metabolism. Energy is no more *stored* away in coal or starch than it is in the oxygen which is required to combine with it during combustion. Every block of stone, for that matter, may be said to contain energy if one could only find some element to combine with it as easily as oxygen combines with coal. It is perhaps best to consider that each oxygen atom (or any other atom) contains a certain definite amount of energy at a certain temperature. Energy in the form of heat is either added to or taken from every oxygen atom according as the surrounding temperature rises or falls. When a carbon atom unites with another atom or group of atoms it loses some of its energy, whilst during dissociation of a carbon compound the carbon atom before it becomes free must have sufficient energy restored to it to bring it back to its normal amount for that particular temperature. The amount of energy in an atom is constant for all atoms of the same kind, but it is more than probable that the amounts are different for different atoms. Energy in the form of emanations is continually given off from radio-active elements. This is the only case known so far in which energy is available without chemical union, but even here the energy is probably a manifestation of chemical change—the element radium, for instance, changing into another element.

Respiration and Evolution.

Respiration will now be reviewed throughout animal and plant life, taking respiration to mean simply the interchange of gases in each living cell. Facility for the supply of oxygen to the tissues must therefore be a concomitant of complexity in structure. Thus every step in evolution must in reality be preceded by or closely connected with some provision for supplying oxygen to every cell in the organism.

In Amœba or any unicellular animal or plant respiration is usually very simple. Such organisms can only live in water. Now all water contains air and therefore oxygen dissolved in it to a slight extent, and this is the only oxygen which is available for aquatic life of any kind, whether plant or animal. The oxygen of composition of water is never utilised in respiration. For such water organisms, therefore, the surrounding medium contains a practically unlimited supply of oxygen, and is so vast that the carbon-dioxide put out into the medium is quickly removed from the neighbourhood of the organism. Whether the interchange of gases takes place only at the surface of such organisms is not known, but it is hardly probable, considering that the vital functions of protoplasm are carried on throughout its whole mass.

In the simpler multicellular animals and plants where there is some differentiation of the tissues the massing of the cells is never so great as to cut off the internal cells from contact with water. In Volvox, which is a colony of unit cells, the cells are arranged in the shape of a hollow sphere, the space inside being filled with water. In Hydroids, Sponges, &c., there is also an internal cavity in which a flow of water is continually kept up, and this constitutes not only a respiratory current for internal cells but also serves as the nutritive current. In star-fishes, where more differentiation has occurred and the internal cells are further removed from the exterior and where there is a special nutritive canal, respiration has been arranged for by a specially contrived system of water-vessels through which water is kept continually moving. This system, which is also used in the peculiar locomotion of the animal, is known as the water vascular system.

So far, then, the living cells of the organisms considered receive their supply of oxygen by contact with the medium in which they live. Animals and plants of more complex structure have now to be considered. Provision for respiration must always keep pace with increase of complexity of structure.

In plants, contact of the living cells with the surrounding medium either of air or water is relied on. Of course, respiration is practically absent from seeds, dried-up moss plants, &c. so long as they remain desiccated. In mosses the leaves are seldom more than one cell in thick-

ness. In higher-land plants the living cells are generally so arranged that small places are left between them. These spaces are filled with air and are connected with each other and with the exterior by special contrivances in different parts of the plant. In the leaf minute pores are found in the outside skin through which air percolates into the leaf tissues and so to the more remote intercellular spaces. In thicker stems, however, larger openings are actually formed in the bark, and loose tissue is exposed to the air through which air can also percolate to the more internal intercellular spaces. The pores in the leaves are known as stomata, and the openings in stems are known as lenticels. In very thick trunks, however, where there is a thick bark, it is not so apparent how air obtains an entrance. It must be noted, however, that in a trunk living cells are only found as a fairly thin layer just inside the bark, the centre of the tree consisting of dead and empty cells. It is quite probable that the living cells being close to the water-conducting tissue obtain their supply of oxygen from the water as it passes upwards. A gum-tree has a closely set bark of at least an inch in thickness, in which there are no lenticels. The living cells of roots are dependent on the air found between the particles of soil, except in the case of thick roots, where the water current may be again utilised. However, some trees which live in water-logged soil and deoxygenated mud send up a special kind of branch from the roots into the air provided with special aerating tissue. Such roots are called respiratory roots, an example of which is found in the Mangrove. In water plants with deep-seated tissues large spaces are always found filled with air. These, of course, may also be of service in keeping the plants more or less erect in the water. Some terrestrial plants too, such as grasses, have hollow stems. Although this may serve as an aid in respiration it is probable that this structure is more for the purpose of economy in building.

In animals a new method of aeration of the deep-seated tissues now appears. That is by a liquid which can carry in it more oxygen than can be carried by water. In the simplest kind of animals using such a means this liquid is found permeating the tissues and filling large irregular spaces in the tissues. An advance on this is found in animals in which the liquid is conveyed to all parts of the body by a ramifying system of tubes, so that eventually each cell comes in contact with this oxygenated liquid. The oxygen in the liquid, of course, comes from the air, and it now becomes a question of keeping up a constant supply of oxygen or air to this liquid. The whole secret of this liquid carrying oxygen about lies in the fact that it contains a peculiar chemical crystalline compound either dissolved in it or contained in tiny special cells floating about in it. This substance is hæmoglobin, and it has the property of easily combining with oxygen and as easily giving it up again to the cells with which it comes in contact.

Another property of the liquid is that of absorbing carbon-dioxide and giving it up again on exposure to the air. It is necessary, therefore, for this liquid to course through the tissues and afterwards to be exposed to the air, and it is sufficient if this exposure takes place through a very thin skin. In this way oxygen is provided for the living cells and carbon dioxide carried away. The liquid thus described is, of course, blood, and the cells in it are known as corpuscles, the colour of the hæmoglobin being red. With increased complexity of structure then, in animals, another requirement become apparent, that is, provision for the exposure of the blood to an oxygen-containing medium. Another requirement is a means for keeping up a continual flow of the blood through the tissues. In worms there is a blood system in which the hæmoglobin is dissolved in the liquid. The circulation is provided for by several pairs of contractile sacs found in certain places in the course of the blood system. There are no specialised organs by which exposure of the blood takes place. The blood is carried to the sub-epidermis of the whole body, throughout which it is distributed by a ramifying system of capillaries. The epidermis and cuticle are sufficiently thin to allow of the diffusion of gases between the air and the blood.

It would appear that blood almost from its first appearance assumed another important function besides that of a respiratory medium; that is, of carrying nutritive material in solution to all parts of the body. This food supply, of course, enters the blood from the seat of digestion in an assimilated form. In animals with a blood system the decomposition products of metabolism are in greater variety than those of plants, and it is necessary for these products to be removed from the blood in which they have been dissolved. For this purpose another organ has arisen called an excretory organ, or kidney. All blood eventually passes through the kidney, and in its course has the effete products, chiefly urea, removed from it, and afterwards these are removed from the body. In simpler animals, such as the worm, the kidney is represented by one or more tubes called nephridia.

In the Oyster family parts of the body are specialised for exposure of the blood to the surrounding medium, *i.e.*, water. These specialised organs are known as gills and consist of filamentous structures in contact with the water, and in which the blood circulates in fine capillaries; and thus a large surface is provided for exposure. A constant flow of water is kept up over the gills by the surface of the gills being covered with vibratile cilia. Circulation in the blood system is provided for by a single muscular contractile sac called a heart, which in this family is of a simple type. In Lobsters and allied animals gills are also found in the form of feather-like structures enclosed in a sort of gill-chamber by a portion of the calcified cuticle. A flow of water is kept up over the gills by the

continual working of a special oar-like organ. In fishes, also, exposure of the blood is carried on by means of gills which are situated in the head-region and enclosed in a gill chamber. This chamber is in connection with the cavity of the mouth. Water is taken in by the mouth, the mouth closed, and the water forced through the gill chamber, the alimentary canal, of course, being kept closed during the process. This opening and closing of the mouth has become quite mechanical in fishes. Respiration being taken to mean the interchange of gases taking place in each individual living cell, it cannot be correct to consider the gills of fishes, &c., as respiratory organs. The gills furnish a medium for the interchange of gases between the blood and the water, and this process may therefore be termed breathing as distinct from respiration.

In insects the blood does not go to any specialised breathing organ, but instead there is found ramifying throughout the body a system of fine tubes carrying air and connected with the exterior. These tubes, so to speak, themselves seek out the blood and the blood tissues in every part of the insect's body, penetrating to the tips of the antennæ and of the legs and entering the most delicate tissues. The want of an arterial system is compensated for as well as conditioned by the extraordinary profuse branching of these tubes or trachea. Most aquatic larvæ of insects breathe by means of tracheal gills or branches, which are either filamentous or leaf-like appendages containing trachea. In some insects such as the dragon-fly and grasshopper there is a rhythmical rise and fall of the upper and lower walls of the abdomen, during which the air enters and passes out of the air openings or spiracles on each side of the body.

In Frogs and Toads, although breathing in the tadpole stage is by means of gills, the land habit of the adult requires a different means, as the external medium is now air instead of water. For this purpose two large distensible air sacs are found inside the front part of the body and connected directly to the cavity of the mouth. These sacs are emptied and filled with air alternately by mechanical movements connected with the floor of the mouth and nostrils. These sacs are called lungs, and their internal surface is somewhat increased by ingrowths from the walls. It is to the walls that deoxygenated blood is sent from the heart and distributed by fine capillaries, and it is there that the interchange of gases in the blood takes place. The oxygenated blood from the lungs then returns to the heart to be sent to all portions of the body. The heart is now a highly differentiated muscular organ. In these animals a certain amount of breathing is also carried on in the skin where an interchange of gases between air and blood can take place. This is said to be the only means of breathing during hibernation in winter. In birds the lungs are solid, spongy organs, only slightly distensible, in which air tubes ramify, the tiny branches ending in small blind dilatations known as alveoli. It is in these

alveoli that the interchange of gases takes place, the walls being closely reticulated with fine blood capillaries. The air tubes are all connected with a main tube or bronchus which is connected with the mouth. In addition the main bronchus also gives off branches which end in a series of thin-walled air sacs which lie in the body cavity and are in communication with the pneumatic cavities of the bones.

In mammals the structure of the lungs is somewhat similar to that of birds, but the lungs are more distensible and are separated from the viscera of the body by a transverse muscular partition called the diaphragm, which helps in the mechanical part of breathing. In some mammals in addition to the excretion by the kidneys some of the decomposition products of metabolism are removed by the agency of the skin through the process of perspiration.

In conclusion, it should be noted that respiration is not a function of any particular organ of a body but is a process going on in each individual cell. Thus the lungs should not be called the organs of respiration—they are only accessory organs. The kidneys might just as well be considered as further organs of respiration in so far as they remove the decomposition products indirectly from the respiring cells, and the heart in so far as it pumps the respiring medium through the body.

Summary.

1. The energy required in the metabolism of colourless cells is not obtained from the sun either directly or indirectly.

2. The protoplasm in colourless cells only uses energy set free by some chemical union taking place either in the cell or by the introduction of external elements into the cell. In no case is energy obtained by the decomposition of substances in the cell, as indeed energy is required to bring about such decomposition.

3. Energy is not required for synthesis of compounds for which chemical affinity is responsible, although undoubtedly chemical affinity is inextricably connected with energy.

4. No plant substance contains a store of directly available energy.

5. Respiration is not a process apart from nutrition. The term respiration should be used exclusively to mean the interchange of gases taking place in each individual cell.

6. That water is the respiratory medium for a large number of the living cells in trees.

Statements in Pfeffer's "Physiology of Plants," vol. i., which, according to this paper, cannot be considered correct:—

Page 295. "Carbon compounds provide both energy and material for growth, so that, &c."

Page 299. "The chemical energy contained in the organic or inorganic substances produced by the partial or complete decomposition of organised bodies is in all cases derived from the work done by the absorbed sunlight."

Page 293. "Organic food provides plastic and constructive material, and at the same time a supply of potential energy."

Page 291. "Every chemical decomposition affords a supply of energy to the plant."

Page 292. "A fungus decomposes a portion of this nutriment in respiratory and other processes, and so obtains the energy necessary for the synthesis of carbohydrates, &c."

Page 293. "Carbon-dioxide and water are synthesised by green plants by means of radiant energy from the sun."

Page 297. "In order to supply the energy necessary for the maintenance of life upon the earth, enormous masses of organic material must be daily decomposed into carbon-dioxide and water."

Page 443. "It is mainly owing to the profound decompositions which respiration and fermentation induce that the chief supply of energy is obtained for vital activity and metabolism in general."

Page 578. "Fermentation is a process by which many aerobic and anaerobic plants are able to obtain a supply of energy by decomposing the greater part of their food into alcohol, &c."

ROYAL SOCIETY OF SOUTH AFRICA.

PRESIDENTIAL ADDRESS.

By S. S. Hough, F.R.S.

(Read April 17, 1910.)

The retiring President delivered his address :—

I should like to-night to have traced the development of our Society from its small beginnings in 1878 to the present time, a growth with which, however, our new President has been so intimately associated that it is perhaps more fitting that I should leave this subject to be dealt with by him on a future occasion. There is, however, at least one matter to which I feel that reference should be made to-night. Those of us who were concerned in the drafting of our new constitution decided to follow as closely as our modified circumstances would permit the model furnished by the Royal Society of London—a Society which has uniformly secured the confidence of scientists, administrative bodies, and the public as representative of the highest interests of true science. Partly at least as a result of this course, we have been enabled to approach the Union Government with a request for financial assistance, which I am pleased to be able to record, as you will see from the Treasurer's report, has been willingly accorded. It has been decided by the Council that the funds thus raised should form the nucleus of a fund which it is hoped may be added to from other sources, and which should be earmarked for the purpose of assisting research work in science. A scheme for its administration, in which the co-operation of other bodies, scientific and educational, in South Africa is invited, has been prepared by the Council. The applications already received for assistance from this fund testify as to its usefulness in assisting what may perhaps be described as personal researches, as distinct from those more organised researches, such, for instance, as those conducted in the public laboratories directly subsidised by Government.

I pass on now to the subject which I have selected on which to address you to-night, and which I propose to entitle—

"Some Recent Improvements in Transit Observing."

Whenever I happen to be in Cape Town about midday I notice a certain instant when almost every one, who is the happy possessor of one, proceeds to take his watch from his pocket and ascertain its indications. He is prompted to do so by the firing of the gun on Signal Hill, and it is gratifying to me to observe the confidence which is always placed in the correctness of the time as indicated by that gun.

True, there are occasions when it misses fire altogether, and it has been known to go off of itself, or fire to a false signal preceding the signal which is intended to discharge it. Such cases are, however, rare, and the resulting uncertainty when they occur is usually so great as to deceive nobody.

This gun, as most of you know, is fired by an automatic electric signal transmitted from the normal mean time clock at the Royal Observatory, the same signal being also transmitted to the Docks, where a ball is dropped, to Simonstown, to Port Elizabeth, and to East London.

An automatic return signal from the Dock Time Ball, as well as observations both of the flash and report of the gun, and monthly returns from outlying stations, indicating the time shown by reliable chronometers at which the signals are received, combine to assure us at the Observatory that, except in cases of accident, the signals actually received at these distant stations correspond in time with those sent from the mean time clock.

As this daily signal governs the whole of the time service—railway time, telegraph time, &c.—it is incumbent on the Observatory staff to ensure that the indications of the clock should not be merely regularly transmitted—a responsibility which, after all, attaches more closely to the telegraph department which provides for their transmission—but that they should be correct indications of the true statutory time. It would be quite safe to say that, with the precautions adopted for this purpose, the error in these signals never attains the limit of half a second, and but rarely reaches one-fifth part of a second.

Now, no existing clock could be relied on, however carefully mounted and adjusted, to secure this accuracy for any continued length of time, and it is therefore necessary to have recourse to daily astronomical observations to ascertain the errors of our clocks, which may then either be corrected or allowed for, as may be most convenient. In fact, the only timekeeper on which we can sufficiently rely is the earth itself in its diurnal rotation, and the most direct method of accurately reading this

time-piece is by means of the transit instrument. This instrument, as it were, forms the indicator, or "hand," of the clock, whose "face" is the sky itself, while the stars correspond with a series of irregularly placed graduation marks on the dial.

With a transit instrument on stable foundations in conjunction with data furnished by the various nautical almanacs, it is not a difficult matter at any time when weather permits to obtain time determinations with a precision exceeding that quoted above as illustrative of the precision attained in the daily time service.

Our usual practice for this purpose is to endeavour to secure an accuracy which would exclude errors of one-tenth part of a second, and doubtless this precision is attained in the majority of cases, except where long-continued cloudy weather prevents a direct reference to the sky and forces us back on the use of our clocks.

When, however, a higher degree of precision in transit-observing is desired, difficulties of a complex character at once begin to present themselves, and it is with the nature of some of these difficulties and the methods adopted for overcoming them that I wish to deal.

In the first place, it is found that two different observers observing almost simultaneously with the same instrument under conditions as nearly similar as can be reproduced, persistently differ to a small but decidedly appreciable extent in their determinations of clock errors.

Two methods of observing have been regularly used until recently. In the older method (known as the "eye and ear" method) the observer listens to the beats of his clock, counting off the seconds, and simultaneously watches the image of a star travelling across the field of his telescope, and estimates to the nearest tenth part of a second the instant at which the star transits across a spider-web fixed in the focal plane of the telescope. In the more modern, or galvanic method, the beats of the clock are automatically recorded on a travelling tape or rotating drum, while the instant at which the star reaches the web is similarly recorded on the same tape (or drum) by the observer tapping a key.

A comparison between the two records, from which the error of the clock may be deduced, can then be made at leisure by a method which admits of higher refinement, if necessary, in the subdivision of a second.

Both methods are found to be liable to discordances of a similar character. It is not uncommon with either method to find two experienced observers whose determinations persistently differ by as much as a quarter of a second, a quantity by no means to be disregarded when even a precision of only one-tenth part of a second is sought.

A far higher accuracy than this must be aimed at in observations required, for instance, in the precise determination of terrestrial longitudes, or in observations required for correcting the tabular positions of stars as

contained in the fundamental catalogues of stars on which the almanac data are based. Were the effects of these personal discordances absolutely uniform for any observer, their resulting effect on either of the operations just referred to could be reduced to zero—in the former case by duplicating the programme and interchanging the observers at the two stations whose difference of longitude is under investigation—in the latter by relying only on differential observations in which each observer's work is combined only with his own determinations of clock error.

There exists, however, a further complication, the discovery of which resulted from the comparison of such differential observations with differential observations of a different character, not dependent on time observations but on accurate micrometric measurements made either on the sky itself or on photographic representations of it. There was a general tendency for the apparent places of the fainter stars in relation to the brighter stars, as determined by the transit observers, to lag behind their positions as determined by other methods. That this tendency could be traced to inaccuracy in the meridian observations was established by covering the object-glass of the telescope with wire-gauze screens, by means of which the apparent brightness of the brighter stars could be reduced to correspond with that of the fainter stars. When this precaution was adopted the anomaly practically disappeared, and the method afforded a means of accurately estimating its amount. This was found to be similar in kind for all observers, but to vary considerably in amount from one observer to another.

To obviate difficulties resulting from these "personal" discordances an entirely new method of transit observing has been devised by Messrs. Repsold, of Hamburg. In place of the fixed reticule of webs in the field of the telescope a single moving web is used which the observer can move at will by turning of a graduated drum-head. As this drum-head is turned a series of "make" and "break" signals is transmitted electrically to the recording tape of a chronograph side by side with similar signals registering the beats of the clock. Each "make" and each "break" corresponds with a definite position of the rotating drum-head, or, what corresponds thereto, of the travelling wire. The operation of observing then consists in turning the drum-head by hand so that the star under observation is continually bisected by the travelling web; the clock times at which it reaches definite positions, these definite positions no longer, however, being marked by fixed webs, are then automatically registered on the chronograph.

The method has been extensively used in field operations for determining terrestrial longitudes with satisfactory results, and is already adopted in several of the leading observatories.

The method may, perhaps, be compared to that of a gunlayer on board

a battleship, who keeps his gun continually pointed on a moving target, so that a hit may be secured at any moment the gun is discharged, say, from the conning tower of the ship.

A more recent innovation has been the introduction of a mechanical method of driving the moving wire at a speed which could be adjusted to correspond with that of the apparent motion of the star in the field of the telescope, and to provide means by which the observer could instantaneously bring the web into exact coincidence with the moving star. If the speed adjustment is then exact, no further action on the observer's part is necessary, but if inexact he is able to correct the movement from time to time in the course of a transit, the results involving such corrections being automatically recorded by the self-registration method on the chronograph.

The new Transit Circle of the Cape Observatory, the erection of which was commenced in 1901, was designed to be operated by the methods which I have been endeavouring to explain to you.

Owing to the necessity for the completion of earlier programmes and the time requisite for preliminary investigation of the instrument, it was not until the beginning of 1905 that a regular observing programme with this instrument was begun. Even then the instrumental equipment was not complete. The earlier attempts at providing a satisfactory mechanical movement for the travelling wire had not proved successful, and it was therefore necessary to commence with the use of the hand-driven web. The programme of work was, however, so arranged as to bring out the capabilities of this method when pushed to its highest refinements.

The immediate object of this programme was the formation of a fundamental catalogue of a selected series of stars. This required not only that the observations should be made with the highest precision attainable, but that they should be so arranged as to be self-sustaining in all respects, *i.e.*, that they should not be made to depend on existing almanac data, but should rather be available for improving them. It was judged expedient to push the working programme to completion by the methods under which it was begun before proceeding with further experimental work. With the exception of a short interruption in the course of the year 1907, this occupied the observing staff until the end of the year 1910.

In the meantime, however, an improved driving apparatus was designed and constructed. This was readily adapted to the instrument, and brought into experimental use from the commencement of the year 1911. Special devices, to which I shall refer later, were included to overcome some of the difficulties met with in the earlier experiments.

Now I wish to call your attention to a few of the results obtained in relation to personality in determining time or clock error.

The last extensive series of time determinations with the old transit instrument, made by observing transits over fixed webs with chronograph and key, was made in the year 1906, and seven regular observers shared the work. From a discussion of the year's observations, persistent personal differences amounting in the extreme to as much as 0·23 s. were found to exist.

In the years 1908 and 1909 six regular observers shared the transit work, working by the travelling wire method, with hand guiding. An independent discussion of each year's observations led to the following determinations of the personal discordances:—

*	1908. s.	1909. s.
C.	−0·007	−0·004
A.P.	+0·014	+0·014
R.C.	+0·013	+0·010
A.W.	−0·036	−0·035
M.	+0·023	+0·026
J.W.	−0·008	+0·001

Notice here that the extreme discordances between different observers amounts only to 0·06 s., *i.e.*, about a quarter only of the similar discordance found in using the older method. The close reproduction of the results derived in the two years indicates, however, that, small as the residual phenomena are, they are real and not merely illusory results obtained by pressing the accuracy of the reductions to an unjustifiable number of decimal figures.

Coming now to personal errors as dependent on the magnitude of the stars under observation, it was found from a special series of observations in 1906, in which five different observers took part, that between the range of magnitude of the bright clock stars and the faintest stars that can be conveniently observed, the discordances amounted at most to 0·03 s.,† and the reality of this quantity was by no means fully established. With the older method of observing, persistent discordances, over the same range of magnitude, of 4 or 5 times this amount are not uncommonly shown.

* The initial letters refer to the following observers:—

C.	=	Mr. W. H. Cox.
A.P.	=	Mr. J. A. J. Pead.
R.C.	=	Mr. R. W. Cheeseman.
A.W.	=	Mr. A. J. Wilkin.
M.	=	Mr. H. F. Mullis.
J.J.	=	Mr. J. W. Jackson.
J.W.	=	Mr. J. C. Wood.
S.	=	Mr. F. H. Scragg.

† Monthly Notices of R.A.S., lxvii., p. 379.

I come now to the observations made during the year 1911, where the Repsold method, accompanied by the use of the mechanically driven web, has been employed. Seven observers took part in the observations, which were primarily concentrated on a series of close circumpolar stars, but included also exact time determinations. Whenever possible the clock error was independently observed by two different observers on each observing night, so as to afford a *direct* comparison between the results obtained by the different observers. A discussion of these comparisons has yielded the following determinations of the personal discordances :—

			s.
C.	=	.....	+0·008
A.P.	=	.....	+0·007
R.C.	=	.....	−0·011
A.W.	=	.....	+0·006
M.	=	.....	−0·005
J.J.	=	.....	−0·008
S.	=	.....	+0·001

The extreme discordance here shown is under two-hundredths of a second, while it is very doubtful whether this may not be a result of the inevitable accidental errors of the observations, which would be still further reduced had it been possible to obtain a larger number of comparisons.

I have confined my attention so far to the aspect of personal equation as it affects rapidly moving stars, such as are always used for exact time determinations. The Repsold method of observing was primarily devised for the latter purpose, and at the time it was brought into use at the Cape I was unacquainted with any attempts to extend its use to the slow-moving stars surrounding the pole. The accurate observations of these stars, especially in the direction of Right Ascension, presents special difficulties, while it is of special importance in that the poles form the principal reference points in the sky to which all exact observations are referred. Considerable doubt as to the positions of the principal southern circumpolars, as given in the almanacs, existed in my mind, and it was thought that the new Transit Circle, with its elaborate system of meridian marks, the high stability of which had been fully established, would soon serve to settle these doubts either one way or the other.

A series of experimental determinations of azimuth was attempted during the winter months of 1907. In order to eliminate errors due to the tabular positions of the stars observed, the device was adopted of observing the same star at upper transit in the evening, and again twelve hours afterwards at lower transit in the morning, or vice versa. It soon

became apparent that the observations, now taken by the Repsold method with hand guiding, could not be reconciled within reasonable limits with earlier observations taken by the older methods. Though instrumental defects were suspected, which, however, could not be located, it was fully apparent that the discordances were in a large measure of a personal character.

The attempt to follow up these discordances was abandoned at the time, it being thought that the discrepancies could be more effectively dealt with when a suitable mechanical movement, which was at the time in course of construction, was available. The experience, however, led me to doubt whether the Repsold method, either with or without clockwork movement, could be effectively used for accurate determinations of the Right Ascension of slow-moving stars. In the case of equatorial stars, the observer at the telescope need only concentrate his attention for a short interval, say some eight or ten seconds at a time, whereas the observation by strictly similar means of the closest circumpolar on our working list would need highly concentrated attention over some ten minutes.

This, as may be readily judged, either put an inordinate strain on the observer, or resulted in very unreliable observations.

The plan adopted for the removal of this difficulty was to revert in the case of circumpolar stars to the older methods of chronograph and key adopted for clock stars. The chief difficulty in relation to the circumpolars is that, though they are relatively free from apparent motion, they are not absolutely so, and the personality seemed to be mainly due to this small residual motion which they possess. Of course they could not be either hurried or reduced to complete rest, but an alternative plan was available of utilising the mechanical movement provided for observing clock stars to give a definite and comparatively rapid motion to the travelling wire. It thus became possible to accurately observe the time of transit of the moving wire over the relative fixed star instead of the moving star over the fixed wire. Of course the personal errors with which I have been dealing to-night would affect such an observation, but there is an important differentiating feature.

A wholesome rule which has been laid down for all measurements of precision for the elimination of systematic errors is "*reverse wherever possible.*" Even unrecognised sources of error may often be eliminated by the adoption of this expedient, and practically all the sources of error that I have been discussing to-night could be thus eliminated if we could include under the heading of *possibility* some means of reversing the direction of rotation of the earth itself.

When, however, the significant part of the apparent motion is not that due to the earth, but to that mechanically imposed on the moving web in

a telescope, such a reversal as I have imagined can be comparatively easily secured.

A device to obtain this end was attached to the instrument and utilised throughout the observations of 1911, and all observations were made by means of an equal number of transits in each direction, right to left and left to right. Nearly two hundred comparisons were made between pairs of observers, each of the two observers observing the same star at the same transit over different parts of the telescope field. A discussion of these comparisons has yielded the following results for the apparent personal discordances between the different observers. In order to make the results strictly comparable with those previously exhibited they have been "reduced to the equator."

Personal Discordances for Circumpolar Stars.

			$\Delta\ \alpha \cos\delta$ s.
C.	=	.....	−0·001
A.P.	=	.....	−0·004
R.C.	=	.....	−0·012
A.W.	=	.....	+0·011
M.	=	.....	+0·006
J.J.	=	.....	−0·007
S.	=	.....	+0·008

It will be seen at once that the outstanding discordances are of a scarcely detectable character, and that practically we may consider the problem of the elimination of personal errors to have been solved.

The discussion of the observations made with the new Transit Circle, since it was first brought into use, which is now in progress in connection with the formation of a catalogue of results, has yielded several results of interest. For instance, I should like to have given some analysis of the performance of that essential accessory to every transit circle, viz., its clock, and to have exhibited figures indicative of the general stability of the instrument. The time at my disposal has, however, compelled me to restrict this address to-night to the one aspect of meridian observing, viz.: the elimination of the personal errors of Right Ascension observations.